

MOLECULAR BONDING SYSTEM®

Innovative Technology Evaluation Report

**National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268**

NOTICE

The U.S. Environmental Protection Agency through its Office of Research and Development under the auspices of the Superfund Innovative Technology Evaluation (SITE) Program funded the research described here under Contract No. 68-C5-0001 to Science Applications International Corporation (SAIC). It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
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ABSTRACT

This project consisted of an evaluation of the Molecular Bonding System® (MBS®) developed by Solucorp® Industries Ltd. to reduce the leachability of heavy metals in soils and other solid wastes. As a part of this evaluation, a demonstration of the technology was conducted by the SITE Program at the Midvale Slag Superfund Site in Midvale, Utah. The overall goal of the demonstration was to evaluate the effectiveness of the MBS process in treating approximately 500 tons each of three hazardous wastes/soils at the Midvale Slag Superfund Site. In addition, demonstration results and other sources of cost information were used to develop detailed cost estimates for full-scale application of the technology. Like other solidification/stabilization (S/S) technologies, the MBS process does not reduce total metals concentrations but instead reduces the leachability of the metals. Therefore, the Toxicity Characteristic Leaching Procedure (TCLP) and Synthetic Precipitation Leaching Procedure (SPLP) were used to evaluate leachable concentration reductions of arsenic (As), cadmium (Cd), and lead (Pb).

The primary objective of the demonstration was to demonstrate that the mean concentration of TCLP leachable Pb in each of three wastes/soils treated by the MBS process is less than the regulatory limit of 5 milligrams per liter (mg/L), at a 90 percent confidence level (CL). The secondary project objectives were to:

- 1) Measure TCLP, SPLP, and total metals concentrations (As, Cd, and Pb) and pH in untreated waste/soil (results from these samples were used as a "baseline" to interpret treated sample results.
- 2) Measure TCLP metals concentrations (As and Cd) and pH (TCLP) in MBS-treated wastes/soils.
- 3) Measure SPLP and total metals concentrations (As, Cd, and Pb) and pH (SPLP and total) in MBS-treated wastes/soils.
- 4) Measure hydraulic conductivity and unconfined compressive strength (UCS) in MBS-treated wastes/soils.
- 5) Measure density in the untreated and MBS-treated wastes/soils.
- 6) Measure the volume increase of each treated waste/soil that could be attributed to the MBS process using process measurements (mass throughput in tons, MBS agent addition in pounds, and water addition in gallons) and density measurements performed on treated and untreated sample composites.
- 7) Measure leachable metals (As, Cd, and Pb) concentrations in the leachate from a Multiple Extraction Procedure (MEP) test performed on each treated waste/soil.
- 8) Measure reactive sulfide in untreated and treated composite samples.

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ACRONYMS AND ABBREVIATIONS

Ag	silver	CLU-IN	Cleanup Information
AOC	area of contamination	cm/sec	centimeter per second
AQ	air-quenched	Cr	chromium
ARAR	Applicable or Relevant and Appropriate Requirement	Cu	copper
As	arsenic	CW	Calcine Waste
ASTM	American Society for Testing and Materials	CWA	Clean Water Act
ATTIC	Alternative Treatment Technology Information Center	EPA	U. S. Environmental Protection Agency
Ba	barium	ft ²	square feet
BD	baghouse dust	gal	gallon
BDAT	Best Demonstrated Available Technology	gpm	gallon per minute
BLW	Butterfield Lumber Waste	hr	hour
BOR	Bureau of Reclamation	H ₂ S	hydrogen sulfide
CAA	Clean Air Act	ICP	inductively coupled plasma
CAMU	corrective action management unit	ITER	Innovative Technology Evaluation Report
Cd	cadmium	lbs/ft ³	pounds per cubic foot
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	LDRs	Land Disposal Restrictions
CFR	Code of Federal Regulations	LRL	laboratory reporting limit
CI	confidence interval	MBS	Molecular Bonding System
CL	confidence level	MCL	maximum contaminant level

ACRONYMS AND ABBREVIATIONS (Continued)

MEP	Multiple Extraction Procedure	QAPP	Quality Assurance Project Plan
mg/kg	milligrams per kilogram	QA/QC	quality assurance/quality control
mg/L	milligrams per liter	RCRA	Resource Conservation and Recovery Act
mg/m ³	milligrams per cubic meter	RPM	remedial project manager
min	minute	SAIC	Science Applications International Corporation
NAAQS	National Ambient Air Quality Standards	SAP	Sampling and Analysis Plan
NPDES	National Pollutant Discharge Elimination System	SARA	Superfund Amendments and Reauthorization Act
NPL	National Priority List	SB	Slag B
NRMRL	National Risk Management Research Laboratory	SDWA	Safe Drinking Water Act
NTIS	National Technical Information Service	Se	selenium
ORD	Office of Research and Development	SF	soil/fill
OSHA	Occupational Safety and Health Administration	SITE	Superfund Innovative Technology Evaluation
OSWER	Office of Solid Waste and Emergency Response	SPLP	Synthetic Precipitation Leaching Procedure
Pb	lead	S/S	solidification/stabilization
PCB	polychlorinated biphenyl	START	Superfund Technical Assistance Response Team
PEL	permissible exposure limit	SW	Miscellaneous Smelter Waste Without Brick
PM ¹⁰	particulates less than 10 microns in diameter	SWB	Miscellaneous Smelter Waste with Brick
POTW	publicly-owned treatment works	TBC	to be considered
PPE	personal protective equipment	TCLP	Toxicity Characteristic Leaching Procedure
ppm	parts per million	TER	Technology Evaluation Report
psi	pounds per square inch		

ACRONYMS AND ABBREVIATIONS (Continued)

TM-SW	SW collected for retest	UDEQ	Utah Department of Environmental Quality
tpd	tons per day		
tph	tons per hour	VISITT	Vendor Information System for Innovative Treatment Technologies
TPH	Total Petroleum Hydrocarbons	WAM	Work Assignment Manager
TSCA	Toxic Substances Control Act	WLS	Wright Laboratory Services
TU	temporary unit	WQ	water-quenched
TWA	time-weighted average	yd ³	cubic yard
UCS	unconfined compressive strength	Zn	zinc

ENGLISH TO METRIC CONVERSION CHART

	English (U.S.)	Metric (SI)
Area:	1 ft ²	9.2903 x 10 ⁻² m ²
	1 yd ²	0.8361 m ²
Concentration:	1 ppm	1 mg/kg or 1 mg/L
Density:	1 lb/ft ³	16.018 kg/m ³
	1 ton/yd ³	1,186 kg/m ³
Flow Rate:	1 gpm	0.22712 m ³ /hr
	1 lb/hr	0.45359 kg/hr
	1 lb/min	0.45359 kg/min
	1 tpd	907.18 kg/day
	1 tph	907.18 kg/hr
Length:	1 ft	0.3048 m
	1 mile	1,609 m
	1 yd	0.9144 m
Mass:	1 lb	0.45359 kg
	1 ton	907.18 kg
Pressure:	1 psi	6,895 Pa
Speed:	1 ft/min	0.5080 cm/sec
Volume:	1 ft ³	2.8317 x 10 ⁻² m ³
	1 gallon	3.7854 x 10 ⁻³ m ³
	1 yd ³	0.7646 m ³

cm = centimeter

ft = foot, ft² = square foot, ft³ = cubic foot

gpm = gallon(s) per minute

hr = hour

kg = kilogram

L = liter

lb = pound

m = meter, m² = square meter, m³ = cubic meter

min = minute

ppm = part(s) per million

Pa = pascal

psi = pound(s) per square inch

sec = second

tpd = ton(s) per day

tph = ton(s) per hour

yd = yard, yd² = square yard, yd³ = cubic yard

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EXECUTIVE SUMMARY

This document presents an evaluation of the Molecular Bonding System® (MBS®) and its ability to chemically stabilize three metals-contaminated wastes/soils during a Superfund Innovative Technology Evaluation (SITE) demonstration conducted by the U.S. Environmental Protection Agency (EPA). The patent-pending Solucorp® MBS utilizes a solid-phase chemical stabilization process to reduce the leachability of heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury, and zinc (Zn) contained in soils, sludges, sediments, and other solid wastes. According to Solucorp, the MBS process rapidly converts metal compounds (e.g., hydroxides, carbonates, and oxides) to less-soluble metallic sulfides.

During the SITE demonstration, the MBS process treated approximately 500 tons each of the following wastes/soils from the Midvale Slag Superfund Site in Midvale, Utah: Soil/Fill (SF), Slag Pile B (SB), and Miscellaneous Smelter Waste Without Brick (SW). The primary objective of the SITE demonstration was to demonstrate that the mean concentration of Toxicity Characteristic Leaching Procedure (TCLP) leachable Pb, in each of the three wastes/soils, was reduced to less than the regulatory limit of 5 milligrams per liter (mg/L), at a 90 percent confidence level (CL). Secondary objectives included measuring the TCLP leachate concentrations of As and Cd, and Synthetic Precipitation Leaching Procedure (SPLP) leachate concentrations of As, Cd, and Pb in each of the treated wastes/soils. An additional 500 tons of SW, designated TM-SW, was treated at Solucorp's expense after the initial treatment of SW resulted in TCLP Cd concentrations exceeding the regulatory limit of 1 mg/L. Solucorp believes that the MBS agent contained a low purity (approximately 50 percent of the target value) sulfide component that resulted in higher than expected leachable metals concentrations in the treated SW. The TM-SW treatment reportedly utilized a higher purity sulfide component in the MBS formula, but was otherwise similar to the SITE demonstration tests.

A Category II Quality Assurance Project Plan (QAPP) was developed for this project. Samples were collected using standardized procedures, and analyses were performed using standard EPA and American Society for Testing and Materials (ASTM) methods to ensure the

representativeness and comparability of the data. For the primary objective, all quality measurements were within control limits. For the secondary objectives, only minor quality issues were identified; their impact on project objectives was negligible. Statistical analyses of results consisted of calculating a mean value for TCLP, SPLP, and total metals. A one-sided upper 90 percent CL was calculated for TCLP and SPLP results; a two-sided 90 percent confidence interval (CI) was calculated for total metals results.

MBS demonstration results indicate that the mean and upper 90 percent CL concentrations of TCLP leachable Pb in each of the three wastes/soils were reduced to less than the TCLP regulatory limit of 5 mg/L. Table ES-1 presents the upper 90 percent CL concentrations of TCLP leachable Pb in the untreated and treated wastes/soils.

Table ES-1. Upper 90 Percent CL Concentrations of TCLP Leachable Pb, mg/L

Waste/Soil	Untreated	Treated
SF	33	0.20
SB	20	1.0
SW	46	3.4
TM-SW	17	0.40

Other demonstration results are:

- The mean TCLP leachable As concentrations increased slightly with treatment, but were below the TCLP regulatory limit of 5 mg/L in each of the untreated and treated wastes/soils.
- The mean TCLP leachable Cd concentrations were below the TCLP regulatory limit of 1 mg/L in both the untreated and treated SF and SB; the mean TCLP leachable Cd concentrations in the untreated and treated SW were 2.1 and 1.1 mg/L, respectively. In the TM-SW, the mean TCLP Cd

- concentrations decreased from 0.5 to less than 0.01 mg/L.
- SPLP leachable As, Cd, and Pb concentrations were below their respective regulatory limits in the treated and untreated SF, SB, SW, and TM-SW.
- The mean volume increases in the treated SF, SB, SW, and TM-SW were 16, 4, 13, and 14 percent, respectively, as compared to the excavated, untreated waste/soil.
- Other than dilution effects, total metals concentrations were not affected by the treatment process.
- Process throughput of untreated waste/soil averaged 52, 59, 56, and 61 tons per hour (tph) for the SF, SB, SW, and TM-SW, respectively.
- Treated wastes/soils passed EPA's Multiple Extraction Procedure (MEP) for As, Cd, and Pb; however, no conclusion could be drawn regarding the effect of treatment on long-term stability because there was no change in the measured leachable metals concentrations from the treated to the untreated wastes/soils.
- Total costs for treatment of approximately 2.07 million tons [1,090,000 cubic yards (yd³)] of SF, SB, and SW were estimated assuming a system capacity of 5,000 tons per day (tpd). Based on scale-up from the demonstration and information from Solu-corp and other sources, costs were estimated at \$20 per ton of waste/soil at the Midvale Slag Site. The total treatment time, including startup and demobilization, is estimated to be 1.7 years.

The MBS process was also evaluated based on the nine criteria used to evaluate technologies in the Superfund feasibility study process. Table ES-2 presents the results of this evaluation.

Table ES-2. Superfund Feasibility Study Evaluation Criteria for the MBS Process^{a, b}

Evaluation Criterion	Performance
Overall Protection of Human Health and the Environment	<ul style="list-style-type: none"> • May provide protection by reducing leachability of contaminant metals. • Stabilizes, but does not destroy contaminants. • Demonstrated ability to reduce leachable concentrations of As, Cd, and Pb to less than their respective TCLP regulatory limits of 5.0, 1.0, and 5.0 mg/L.
Federal ARAR ^c Compliance	<ul style="list-style-type: none"> • May have to meet substantive requirements of a Resource Conservation and Recovery Act (RCRA) treatment permit if treating hazardous waste. • Treated waste should meet Land Disposal Restrictions (LDRs) for leachability of metals. • Technology should meet air emissions limits, using appropriate pollution control technologies. • Compliance with Clean Water Act regulations should be attainable or not applicable.
Long-term Effectiveness and Permanence	<ul style="list-style-type: none"> • Treated wastes/soils pass MEP test; however, no conclusion could be drawn regarding the effect of treatment on long-term stability because there was no change in the measured leachable metals concentrations from the untreated to the treated wastes/soils.
Reduction of Toxicity, Mobility, and Volume through Treatment	<ul style="list-style-type: none"> • Treatment reduces mobility of contaminant metals, reducing routes of exposure. • Treatment increased the waste volume during SITE demonstration by 4 to 16 percent. • Treatment may reduce toxicity by converting some metal compounds to less-toxic forms.
Short-term Effectiveness	<ul style="list-style-type: none"> • Implementation of the MBS technology may produce odor concerns, but air pollution control equipment should ameliorate short-term impacts to human health and the environment.
Implementability	<ul style="list-style-type: none"> • Technology should be implementable at sites with sufficient space for setup, support, and operation. • Technology does not require site infrastructure to operate. • Most equipment components are readily available, allowing faster setup and reduced downtime. • Technology may be amenable to in situ applications.
Cost ^d	<ul style="list-style-type: none"> • The cost of using this technology is estimated at \$20 per ton of material treated.
State Acceptance	<ul style="list-style-type: none"> • Willingness of vendor to perform bench- and pilot-scale treatability tests should increase acceptability.
Community Acceptance	<ul style="list-style-type: none"> • Odor concerns may be raised by community. • Use of the technology to decrease leachability, tied with institutional controls for treated material, should be a readily understandable remediation approach.

a Based on the results of the SITE demonstration at the Midvale Slag Superfund Site

b Information contained in this table should not be used without examining all other parts of a complete treatment alternative.

c ARARs = Applicable or Relevant and Appropriate Requirements

d Actual cost of the technology is site-specific and dependent on soil characteristics and types, total mass, and contaminant concentrations.

SECTION 1

INTRODUCTION

A demonstration of the Molecular Bonding System® (MBS®) was conducted by the U. S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory (NRMRL). Solucorp® Industries Ltd., the developer of the MBS process, was responsible for system installation and operation during the demonstration. EPA's Superfund Innovative Technology Evaluation (SITE) Program conducted sampling, analytical, and report writing activities and evaluation of the MBS process in support of this effort. Science Applications International Corporation (SAIC) was the SITE Program contractor for the implementation of this demonstration.

This introduction provides an overview of (1) the SITE Program, (2) the purpose of this Innovative Technology Evaluation Report (ITER), (3) the MBS process, (4) the demonstration location, (5) demonstration activities, (6) demonstration results, and (7) additional sources of information on the SITE Program and the demonstration. Section 2 presents an applications analysis for the technology. Section 3 discusses the results of an economic analysis of the technology. Section 4 presents the results of the demonstration. Section 5 discusses requirements to be considered when using the technology. Section 6 discusses the status of the technology. Appendix A contains the results of treatability studies performed for the Midvale Slag Superfund Site. Appendix B contains the performance data from the demonstration. Appendix C contains the case studies. Appendix D contains vendor claims for the technology.

1.1 BRIEF DESCRIPTION OF PROGRAM AND REPORTS

In 1986, the EPA Office of Solid Waste and Emergency Response (OSWER) and the Office of Research and Development (ORD) established the SITE Program to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its eleventh year, the SITE Program is helping to provide the treatment technologies necessary to

implement new Federal and State cleanup standards aimed at permanent remedies rather than quick fixes. The SITE Program is composed of four major elements: the Demonstration Program, the Emerging Technology Program, the Measurement and Monitoring Technologies Program, and the Technology Transfer Program.

The major focus has been on the Demonstration Program, which is designed to provide engineering and cost data for selected technologies. To date, the Demonstration Program projects have not included funding for technology developers. EPA and developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. EPA is responsible for sampling, analyzing, and evaluating all test results. The final product of each demonstration is an assessment of the technology's performance, reliability, and costs. This information is used in conjunction with other data to select the most appropriate technologies for the cleanup of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to EPA's annual solicitation. EPA also accepts proposals any time a developer has a Superfund waste treatment project scheduled. To qualify for the program, a new technology must be available as a pilot- or full-scale system and offer some advantage over existing technologies. Mobile technologies are of particular interest to EPA.

Once EPA has accepted a proposal, EPA and the developer work with the EPA regional offices and State agencies to identify a site containing waste suitable for testing the capabilities of the technology. EPA prepares a detailed sampling and analysis plan designed to evaluate the technology thoroughly and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several years, depending on the length of time and quantity of waste needed to assess the technology.

The second element of the SITE Program is the Emerging

Technology Program, which fosters the further investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies can lead to the development of a system ready for field demonstration and participation in the Demonstration Program.

The third component of the SITE Program, the Measurement and Monitoring Technologies Program, provides assistance in the development and demonstration of innovative technologies to improve characterization of Superfund sites.

The fourth component of the SITE Program is the Technology Transfer Program, which reports and distributes the results of both Demonstration Program and Emerging Technology Program studies through ITERs and abbreviated bulletins. A Technology Evaluation Report (TER) was also developed for the MBS SITE demonstration. The TER provides greater detail on the demonstration and presents a complete package of measurement results. The TER is on file at EPA NRMRL.

1.2 PURPOSE OF THE ITER

The ITER provides information on the MBS process and includes a comprehensive description of the demonstration and its results. The ITER is intended for use by EPA remedial project managers (RPMs) and on-scene coordinators, contractors, and others involved in the remediation decision-making process and in the implementation of specific remedial actions. The ITER is designed to aid decision makers in determining whether specific technologies warrant further consideration as applicable options in particular cleanup operations. To encourage the general use of demonstrated technologies, EPA provides information on the applicability of each technology to specific sites and wastes. The ITER includes information on cost and site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology.

This report represents an important step in the development and commercialization of the MBS process. Each SITE demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics at other sites may differ from the characteristics of those treated during this demonstration. Therefore, successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation to estimate the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.3 TECHNOLOGY DESCRIPTION

The patent-pending MBS process uses a proprietary chemical formulation to remediate heavy metal contamination in soils, sludges, sediments, and other solid wastes. Solucorp claims that the MBS technology:

- Chemically converts metal compounds (e.g., hydroxides, carbonates, and oxides) into less-soluble metallic sulfides.
- Does not modify the pH of the waste/soil to achieve chemical stabilization, providing an advantage when treating multiple metals with different solubility points.
- Does not alter the physical properties of the waste/soil during treatment.
- Does not require a curing process.
- Produces a volume increase of less than 5 percent due to the addition of the stabilization chemicals (i.e., the "MBS agent").
- Cannot effectively treat wastes/soils with high chloride content (in excess of 15 to 20 percent).
- Can be implemented in situ. (Note: An ex situ system was used during the demonstration, and this ITER primarily addresses ex situ applications.)
- Can treat certain metals that are present in reduced form [e.g., arsenic (As)] with the addition of an oxidizing agent.

During ex situ applications, treatment occurs onsite in a treatment system comprised of a feed hopper, variable speed conveyers, a storage silo for MBS agent, and a pugmill (see Figure 1 for a schematic of the MBS technology). Excavated soil is transferred to the steel hopper. The material may be transferred from storage piles using a front-end loader, as was done during the demonstration, or direct feed from excavation to the system may be appropriate. Untreated soil is then carried into the pugmill by a conveyor. During treatment, the MBS agent is transferred from the silo into the pugmill using a chemical feed auger. The MBS agent is mixed with the untreated soil in the pugmill. Water may also be added to the pugmill to minimize dust and promote uniform mixing; 15 to 25 per-

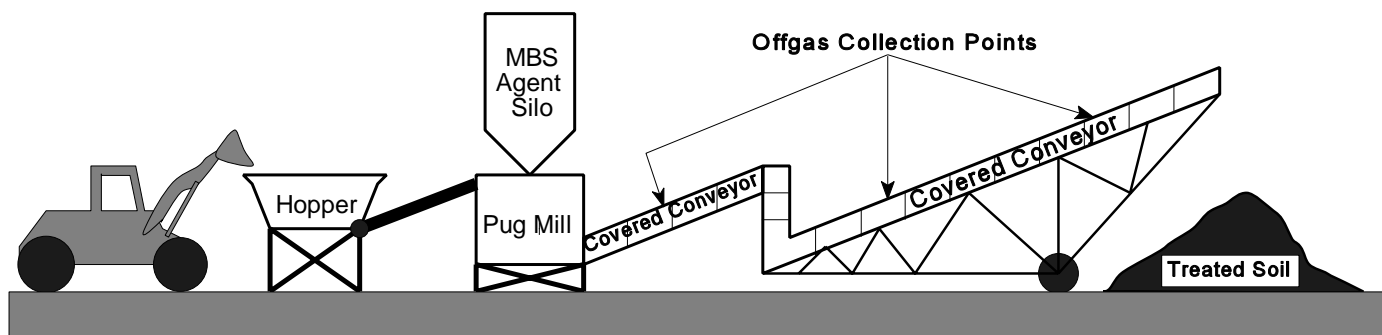


Figure 1. Schematic of the MBS technology.

cent total moisture is optimum. A belt scale is used to monitor the rate at which treated soil exits the pugmill.

Covered conveyors are used to transport treated soil from the pugmill to a temporary storage pile at the end of the process. The conveyors are enclosed and equipped with blowers to minimize fugitive hydrogen sulfide (H_2S) emissions. Emissions are collected from vacuum ports along the tops of the conveyors and discharged into a manifold that serves as the vapor inlet to air pollution control equipment. According to Solucorp, drums of specially-coated carbon may be used to treat H_2S emissions to approximately 2 milligrams per cubic meter (mg/m^3). If air emission standards are more stringent, as was the case during the SITE demonstration, a packed scrubber tower may be used to reportedly reduce H_2S emissions to approximately 1 mg/m^3 . Scrubber water percolates through the scrubber, countercurrent to the vapor stream being treated. Used scrubber water effluent is pumped back to the top of the tower. Effluent vapor is vented to the atmosphere through an opening at the top of the scrubber unit. (Note: The effectiveness of the wet scrubber was not evaluated during the demonstration.)

After treatment, the blended soil may be either returned to the site with an appropriate cover or disposed of offsite in a Subtitle D landfill. The ultimate fate of the treated material will be site-specific and will depend in part on the material's characteristics and site-specific regulations and institutional controls. The volume increase of the soil, due to the addition of the MBS agent, varies depending on the concentration of metals present in the untreated soil. Volume increases observed during the demonstration ranged from 4 to 16 percent of the original excavated soil volume. Larger volume increases may be experienced if an oxidizing agent is needed; however, these increases have not been estimated since oxidation was not performed during the demonstration. Solucorp claims that several types of oxidizing agents can be added during treatment to convert certain metals present in reduced forms (e.g., As)

to improve treatment effectiveness.

1.4 DESCRIPTION OF THE DEMONSTRATION LOCATION

The Midvale Slag Superfund Site is located 12 miles south of Salt Lake City, Utah, in Midvale, Utah. Mining ores were smelted and refined at the 530 acre site from 1871 to 1958. A slag screening operation was later operated at the Midvale site from 1964 to 1992. The processed slag was sold as fill and for use in shot and grit blasting. The processed slag was also used in the construction of railroad beds and road bases.

During refining and smelting activities, large quantities of waste containing elevated heavy metals concentrations were deposited directly on the surface. Soils and groundwater underlying the site were contaminated by these deposits. Currently, a large portion of the site is covered with piles or layers of smelter waste, building demolition debris, and mill tailings.

The site was placed on the Superfund National Priority List (NPL) in 1986. In 1995, a removal action, consisting of onsite solidification/stabilization (S/S) and disposal of contaminated waste/soil in a clay covered disposal cell, was approved. The contaminants of concern in the solid media are As, cadmium (Cd), and lead (Pb). The contaminated media at the site have been divided into the following six categories:

- Calcine Waste (CW) - Roasted arsenopyrite ore
- Miscellaneous Smelter Waste - Tailings transported from the adjacent Sharon Steel site, contaminated baghouse bricks, pure As trioxide, and baghouse dust
- Soil/Fill (SF) - Mixture of slag, tailings, and native

soils

- Baghouse Dust (BD) - Material collected in a "pond" structure washed from the smelter baghouse
- Slag - Water-quenched (WQ) and air-quenched (AQ) slags, iron slag, and copper (Cu) slag
- Butterfield Lumber Waste (BLW) - Contaminated soil and demolition debris from Butterfield Lumber.

Because portions of the miscellaneous smelter waste contain larger amounts of the contaminated baghouse brick, the miscellaneous smelter waste can be broken into two additional subcategories: 1) Miscellaneous Smelter Waste with Brick (SWB); and 2) Miscellaneous Smelter Waste Without Brick (SW).

1.5 DESCRIPTION OF DEMONSTRATION ACTIVITIES

During the SITE demonstration, the MBS process treated approximately 500 tons of each of the following three contaminated wastes/soils from the Midvale site: SF, Slag B (SB), and SW. About 7 weeks after the treatment of these wastes was complete, Solucorp excavated and treated a second batch of the SW (designated TM-SW). Solucorp decided to re-treat the SW after being notified that Cd concentrations in Toxicity Characteristic Leaching Procedure (TCLP) leachates from the treated SW samples exceeded the TCLP limit of 1 milligram per liter (mg/L). Although the re-treatment of the SW was funded by Solucorp, the TM-SW was excavated, processed, and treated according to the same procedures followed by the SITE Program during the original treatment of the SW. To reduce analytical costs, however, the samples were only analyzed for total and TCLP As, Cd, Pb, and pH, and density. The MBS agent used during the treatment of the TM-SW also reportedly contained a higher purity sulfide component than the MBS agent used during the treatment of the SW. Analytical results from samples collected during TM-SW treatment are summarized in Section 4 of this ITER with the demonstration results.

The SF and SB were treated from April 8, 1997 through April 21, 1997. The SW was treated from May 5, 1997 through May 8, 1997, and the TM-SW was treated from June 23, 1997 through June 25, 1997. In total, the demonstration was performed over approximately 18 days, of which 4 days were spent treating the 4 wastes/soils (1 day per waste/soil). The remaining 14 days were consumed by system startup testing and initial equipment calibration checks (3 days), system repairs and operating problems (3 days), system decontamination and calibration checks between wastes/soils and after the last waste/soil (4

days), and delays associated with the delivery of the MBS agent (4 days).

1.6 SUMMARY OF DEMONSTRATION RESULTS

The results obtained in support of the primary objective are:

- The mean and upper 90 percent confidence level (CL) concentrations of TCLP leachable Pb in each of the three wastes/soils were reduced to less than the TCLP regulatory limit of 5 mg/L. Upper 90 percent CL concentrations were reduced from 33, 20, 46, and 17 mg/L in the untreated SF, SB, SW, and TM-SW to 0.20, 1.0, 3.4, and 0.40 mg/L in the treated SF, SB, SW, and TM-SW, respectively.

The results obtained in support of the secondary objectives are:

- The mean TCLP leachable As concentrations increased slightly with treatment, but were below the TCLP regulatory limit of 5 mg/L in each of the untreated and treated wastes/soils.
- The mean TCLP leachable Cd concentrations were below the TCLP regulatory limit of 1 mg/L in both the untreated and treated SF and SB; the mean TCLP leachable Cd concentrations in the untreated and treated SW were 2.1 and 1.1 mg/L, respectively. In the TM-SW, the mean TCLP Cd concentration decreased from 0.5 to less than 0.01 mg/L.
- SPLP leachable As, Cd, and Pb concentrations were below their respective regulatory limits in the treated and untreated SF, SB, SW, and TM-SW.
- The mean volume increases in the treated SF, SB, SW, and TM-SW were 16, 4, 13, and 14 percent, respectively, as compared to the excavated, untreated waste/soil.
- Other than dilution effects, total metals concentrations were not affected by the treatment process.
- Process throughput of untreated waste/soil averaged 52, 59, 56, and 61 tons per hour (tph) for the SF, SB, SW, and TM-SW, respectively.
- Treated wastes/soils passed EPA's Multiple Extraction Procedure (MEP) for As, Cd, and Pb; however, no conclusion could be drawn regarding the effect of treatment on long-term stability because there was no change in the measured leachable metals concentrations from the untreated

ed to the treated wastes/soils.

- Total costs for treatment of approximately 2.07 million tons [1,090,000 cubic yards (yd³)] of SF, SB, and SW were estimated assuming a system capacity of 5,000 tons per day (tpd). Based on scale-up from the demonstration and information from Solucorp and other sources, costs were estimated at \$20 per ton of waste/soil at the Midvale Slag Superfund Site. The total treatment time, including startup and demobilization, is estimated to be 1.7 years.

1.7 KEY CONTACTS

Further information concerning the MBS process described in this report can be obtained by contacting the individuals listed below:

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Information on the SITE Program is also available through the following on-line information clearinghouses:

- The Alternative Treatment Technology Information Center (ATTIC) is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized, searchable source. This data base provides summarized information on innovative treatment technologies. The modem access number is (513) 569-7610. Voice assistance is available at (513) 569-7272. The TelNet number is CINBBS.CIN.EPA.GOV.
- Version 5.0 of the Vendor Information System for Innovative Treatment Technologies (VISITT) data base contains information on 346 technologies offered by 210 developers. VISITT can be downloaded from www.prcemi.com/visitt. Technical assistance or a disk copy of VISITT can be obtained by calling (800) 245-4505.
- The OSWER Cleanup Information (CLU-IN) electronic bulletin board contains information on the status of SITE technology demonstrations. The system operator can be reached at (301) 589-8268. Modem access is available at (301) 589-8366 or www.clu-in.com.

Technical reports can be obtained by contacting EPA-NRMRL's Technology Transfer Branch, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268 at (513) 569-7562.

SECTION 2

TECHNOLOGY APPLICATIONS ANALYSIS

This section provides information on the ability of the MBS process to meet regulatory and operational requirements associated with the remediation of Superfund sites. Subsection 2.1 presents a discussion of the considerations associated with seven major regulatory programs. The operability, applicability, key features, availability and transportability, material handling requirements, site support requirements, and limitations of the MBS process are discussed in Subsections 2.2 through 2.8.

2.1 REGULATORY CONSIDERATIONS

This subsection discusses seven major regulatory programs, starting with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). CERCLA requires compliance with all applicable or relevant and appropriate requirements (ARARs), providing the entrance point for the other regulations discussed in this subsection. Since the MBS process is designed to treat solid-phase materials, emphasis has been placed upon the Resource Conservation and Recovery Act (RCRA) regulations. The other regulatory statutes discussed are the Clean Air Act (CAA), Safe Drinking Water Act (SDWA), Clean Water Act (CWA), Toxic Substances Control Act (TSCA), and Occupational Safety and Health Act (OSHA). Each statute can have corresponding State or local laws that are more stringent or broader in scope than analogous Federal regulations. Because State and local ARARs may be different for each site, only Federal ARARs are evaluated in this document. Table 1 briefly discusses the Federal ARARs that should be considered when using the MBS process at a Superfund site.

2.1.1 CERCLA

CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986, provides for Federal funding to respond to releases of hazardous substances to air, water, and land. Section 121 of SARA, Cleanup Standards, states a strong statutory preference for

remedies that are highly reliable and provide long-term protection. It strongly recommends that remedial actions use onsite treatments that "... permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances." In considering remedial actions, EPA must evaluate the following nine criteria [1]:

- Overall protection of human health and the environment
- Compliance with ARARs
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume
- Short-term effectiveness
- Implementability
- Cost
- State acceptance
- Community acceptance.

An evaluation of the MBS process, using these nine criteria, is presented in Table ES-2 of the Executive Summary. The information in the table, however, should not be used as a substitute for a complete, site-specific analysis of alternatives.

2.1.1.1 ARARs

Of the nine criteria, compliance with ARARs can be one of the most complex to evaluate. ARARs consist of Federal, State, and local statutory or regulatory requirements that must be considered when evaluating potential remedies at

Table 1. Potential Federal ARARs for Use of the MBS Process at a Superfund Site

Process Activity	ARAR	Description	Basis	Response
Waste characterization (untreated waste or soil)	RCRA regulations in 40 CFR ^a part 261 or State equivalent	Identification and characterization of the waste or soil to be treated.	A requirement of RCRA prior to managing the waste or soil.	Characterization must be performed using (1) chemical and physical analyses or (2) knowledge of the process that generated the waste.
	TSCA regulations in 40 CFR part 761 or State equivalent	Standards that apply to the storage, treatment, and disposal of wastes containing PCBs ^b .	During characterization of the soil, PCBs may be identified and, if present above regulatory thresholds (50 ppm ^c for TSCA), the material is subject to TSCA regulations.	PCB analysis of soil must be performed if potentially present.
Storage prior to processing	<90 days: RCRA regulations in 40 CFR part 262 or State equivalent	Standards applicable to the storage of hazardous waste.	Waste or soil that is being managed (e.g., has been excavated) and that meets the definition of hazardous waste must meet substantive requirements of RCRA storage regulations.	Ensure storage containers and tanks are in good condition, waste piles are properly maintained, provide secondary containment (where applicable), and conduct regular inspections.
	>90 days: RCRA regulations in 40 CFR part 264 or State equivalent			
	<1 year: TSCA regulations in 40 CFR part 761.65 >1 year: TSCA regulations in 40 CFR part 761.65	Standards applicable to the storage of waste or soil with >50 ppm PCBs.	Storage must meet structural requirements.	Provide adequate roof, walls, floor, and curbing above the 100-year flood plain.
Waste processing	RCRA regulations in 40 CFR part 264 or State equivalent	Standards applicable to the treatment and disposal of hazardous waste at permitted facilities. ^c	Storage must meet structural requirements and receive an interim remedy waiver.	Provide adequate roof, walls, floor, and curbing above the 100-year flood plain, and receive a waiver prior to 1-year limit.
	CAA regulations or State equivalent	Standards applicable to emissions from treatment equipment.	If the waste or soil has been determined to be hazardous, treatment must be conducted in a manner that meets the substantive requirements ^d of a RCRA Part B permit.	Equipment must be operated, maintained, and monitored properly. Wastes must be stored in accordance with unit ^c -specific requirements.
Management of wastewater			Offgas from treatment may have to be controlled to meet the substantive requirements of air emissions regulations.	Modeling and monitoring may have to be performed; emission control devices may have to be installed.
	CWA regulations in 40 CFR parts 301, 304, 306, 207, 308, 402, and 403 or State equivalent	Standards that apply to discharge of contaminated water into sewage treatment plants or surface water bodies.	Water from air emissions control equipment and decontamination procedures may not meet local pretreatment standards without further treatment or may require a NPDES ^d permit for discharge to surface water.	Determine if the waste water could be discharged to a sewage treatment plant or surface water body without further treatment. If not, the water may need to be further treated to meet discharge requirements.
	SDWA regulations in 40 CFR parts 144 and 145 or State equivalent	Standards that apply to the disposal of contaminated water in underground injection wells.	Injection of wastewater, which may be the preferred option at remote sites, must comply with SDWA standards.	If underground injection is selected as a disposal means for wastewater, testing must be performed and permission must be obtained from EPA to use existing, permitted, underground injection wells or to construct and operate new wells.

^a CFR is the Code of Federal Regulations

^b PCBs are polychlorinated biphenyls

^c ppm is parts per million

^d NPDES is the National Pollutant Discharge Elimination System

Superfund sites. Under SARA, CERCLA response actions must consider and comply with, or justify a waiver from, all ARARs [1].

In most cases, the types and concentrations of contaminants present at the site determine which statutes and regulations are ARARs. Consequently, it is important to characterize media and wastes for additional contaminants [e.g., organic compounds, nontarget metals, and polychlorinated biphenyls (PCBs)] in addition to target compounds. Typically, onsite response actions must comply with the substantive portions of ARARs, while compliance with the administrative requirements (e.g., filing permit applications) is not required. Both the substantive and administrative portions of the ARARs must be satisfied for offsite actions (e.g., hazardous waste must be properly packaged and manifests must be completed for offsite shipment of hazardous waste). ARARs are divided into two categories, applicable requirements and relevant and appropriate requirements.

2.1.1.2 Applicable Requirements

Applicable requirements are the substantive standards that address the specific situation at a CERCLA site. In determining the applicability of a Federal, State, or local requirement, the following must be asked [1]:

- Who is subject to the requirement?
- What types of substances or activities fall under the authority of the requirement?
- What is the time period for which the requirement is in effect?
- What types of activities does the requirement mandate, limit, or prohibit?

Once a requirement has been deemed applicable, it must be followed or waived.

2.1.1.3 Relevant and Appropriate Requirements

If a statutory or regulatory requirement is deemed not to be applicable, a determination of whether it is relevant and appropriate must be made. For a Federal, State, or local requirement that is not applicable to be an ARAR, the statute or regulation must be both relevant and appropriate. In order to be relevant, a requirement must address problems or situations sufficiently similar to the circumstances of the proposed action. For a requirement to be appropriate, it must be well-suited for a site. In determining the relevance and appropriateness of a Federal, State, or local requirement, the following questions must be considered [1]:

- What are the respective purposes of the response action and the requirement?
- Is the site to be remediated of the same type as that regulated by the requirement?
- Are the media affected by the response action and addressed by the requirement the same?
- Are the substances found at the site and addressed by the requirement the same?
- Are the activities proposed for the site the same as those addressed by the requirement?
- Are the types and sizes of structures at the site the same as those addressed by the requirement?
- Are any waivers, variances, or exemptions from the requirement available to the site?
- Is the potential use of the affected resources covered by the requirement?

Once a requirement has been deemed both relevant and appropriate, it must be followed or waived.

2.1.1.4 ARAR Waivers

Recognizing that site-specific factors may require solutions other than those indicated by ARARs, Congress provided six statutory waivers that allow EPA to choose technically and financially preferable options over ARARs. The situations with statutory waivers are [1]:

- Interim Measures (temporary actions where the final actions will meet ARARs)
- Greater Risk to Health and the Environment (when an ARAR is less protective)
- Technical Impracticability (when an ARAR is not feasible from an engineering perspective)
- Equivalent Standards of Performance (for alternate cleanup methods that meet performance standards)
- Inconsistent Application of State Requirements (for State requirements that have not been uniformly applied)
- Fund-Balancing (when the cost of attaining an ARAR does not strike a balance between available trust fund monies and the amount of environmental protection achieved).

2.1.1.5 To Be Considered Materials

Many agencies develop criteria, guidance, and advisories that are not backed by the force of law. The information, however, is often very useful in performing CERCLA cleanups. These "to be considered" (TBC) documents and policies assist in moving from the broad criteria of many ARARs to the specifics of implementation at a site. For this reason, TBCs play an important role in complying with ARARs.

2.1.2 RCRA

RCRA and the corresponding Code of Federal Regulations (CFR) are the primary legislation and regulations governing solid and hazardous waste activities. Subtitle C of RCRA specifies requirements for the generation, transportation, treatment, storage, and disposal (i.e., management) of hazardous waste. Compliance with the substantive portions of these requirements is mandatory for CERCLA sites managing hazardous waste. Since these regulations can significantly impact applications of the MBS process at CERCLA sites, emphasis has been placed on this subsection.

2.1.2.1 Definition of Solid Waste

The applicability of the RCRA hazardous waste regulations to a CERCLA action is determined through a series of decisions starting with the type(s) of material to be managed. In order for material to be subject to hazardous waste regulations, it must first be considered solid waste, or be media (i.e., soil or water) contaminated with solid waste. Solid waste, as defined by 40 CFR 261.2, is any discarded material that is not excluded by regulation of variance. A discarded material is any material which is abandoned (i.e., disposed of, burned/incinerated, or accumulated, stored, or treated before or in lieu of being abandoned), recycled (i.e., used in a manner constituting re-use or burned for energy recovery), or inherently waste-like. Most of the materials suitable for treatment by the MBS process would be considered solid waste under RCRA. All six of the materials identified in Subsection 1.4 as present at the Midvale Slag Superfund Site would be considered solid waste or soil mixed with solid waste. The materials treated during the SITE demonstration (SF, SB, SW, and TM-SW) would be considered by-products and soil contaminated with by-products from industrial operations at the site.

2.1.2.2 Definition of Hazardous Waste

In order to be subject to RCRA hazardous waste regulations, materials that meet the definition of solid waste also must meet the definition of hazardous waste found in 40 CFR 261.3. A solid waste is a hazardous waste if: it is not one of the materials specifically excluded from

hazardous waste regulations (see 40 CFR 261.4(b)); it is listed in 40 CFR 261.31 through 261.33 (referred to as listed hazardous wastes); is a mixture of solid waste and listed hazardous waste (referred to as "the mixture rule"); it is derived from the treatment of listed hazardous waste (referred to as "the derived from rule"); or it exhibits one or more of the four hazardous characteristics identified in 40 CFR 261.21 through 261.24 (referred to as characteristic waste). Media (e.g., soil or water) that contain a listed hazardous waste or display a hazardous characteristic also must be managed as hazardous waste.

2.1.2.3 Excluded Solid Waste

Federal regulations exclude certain types of solid waste from regulation as hazardous waste. Samples of waste to be used in treatability studies are conditionally exempt from Federal hazardous waste regulation (see 40 CFR 261.4(e)). Solid wastes from the extraction, beneficiation, and processing of ores and minerals, commonly known as the Bevill Amendment wastes, are another category of solid waste excluded from Federal hazardous waste regulations. (States, however, have the authority to regulate Bevill Amendment wastes as hazardous by declining to adopt the exemption into their hazardous waste regulations.) In 40 CFR 261.4(b)7, EPA has adopted the following description of "beneficiation" of ores and minerals:

"crushing; grinding; washing; dissolution; crystallization; filtration; sorting; sizing; drying; sintering; pelletizing; briquetting; calcining to remove water and/or carbon dioxide; roasting, autoclaving, and/or chlorination in preparation for leaching (except where the roasting (and/or autoclaving and/or chlorination)/leaching sequence produces a final or intermediate product that does not undergo further beneficiation or processing); gravity concentration; magnetic separation; electrostatic separation; flotation; ion exchange; solvent extraction; electro-winning; precipitation; amalgamation; and heap, dump, vat, tank, and in situ leaching."

The same section defines solid waste from the "processing" of ores as the following (wastes listed in the regulations which appear to be amenable to treatment by the MBS process are presented in bold font):

"slag from primary Cu processing; slag from primary Pb processing; red and brown muds from bauxite refining; phosphogypsum from phosphoric acid production; slag from elemental phosphorus production; gasifier ash from coal gasification; process wastewater from coal

gasification; calcium sulfate wastewater treatment plant sludge from primary Cu processing; **slag tailings from primary Cu processing**; fluorogypsum from hydrofluoric acid production; process wastewater from hydrofluoric acid production; **air pollution control dust/sludge from iron blast furnaces**; **treated residue from roasting/leaching of chrome ore**; process wastewater from primary magnesium processing by the anhydrous process; process wastewater from phosphoric acid production; **basic oxygen furnace and open hearth furnace air pollution control dust/sludge from carbon steel production**; **chloride process waste solids from titanium tetrachloride production**; and **slag from primary zinc (Zn) processing**"[2].

Treatment of these wastes, or soil that displays a hazardous characteristic solely due to the presence of these wastes, would not be subject to Federal hazardous waste regulations. Based upon the available information, it appears that the untreated SB would be excluded from Federal hazardous waste regulations. Since the SF contains slag (which is excluded), tailings, presumably from iron ore processing (which are not excluded), and native soil, its regulatory status with regard to exclusion from hazardous waste regulations is unclear (if the material displays a characteristic of hazardous waste solely due to the presence of the slag, it could still meet the exclusion). The SW does not appear to be excluded from Federal hazardous waste regulations (although the baghouse dust, if produced by air pollution control devices supporting the iron blast furnace, would be excluded). Since the MBS process appears to be suitable for treatment of several Bevill Amendment wastes, RCRA regulations may not be applicable to some applications of the technology (although they may be relevant and appropriate).

2.1.2.4 Listed Hazardous Waste

Of the hazardous wastes listed in 40 CFR 261.31 through 261.33, relatively few are amenable to treatment by the MBS process, like many S/S technologies. Most of the hazardous waste from non-specific sources (F-listed hazardous waste) contain organic compounds of concern. Of the hazardous waste from specific sources (K-listed hazardous waste), the inorganic pigments, iron and steel, primary Zn, secondary Pb, and inorganic chemicals

categories have wastes that appear to be suitable for treatment by this technology. Cost-effective use of the MBS process to treat pure discarded commercial chemical products (U- and P-listed wastes) does not appear to be feasible for the treatment of liquids; the feasibility for powders is not known. Cost-effective treatment of soil contaminated with certain U- and P-listed wastes should be feasible; soil contaminated with As trioxide may require oxidation to improve treatment results.

2.1.2.5 Mixture Rule

A more likely scenario is the use of the technology to treat other wastes or soil that has been contaminated with K-, F-, P-, or U-listed wastes. Under the aforementioned mixture rule, a mixture of solid waste and listed hazardous waste is regulated as hazardous waste regardless of the concentration of listed hazardous waste in the mixture. The untreated SW and TM-SW reportedly contained As trioxide that was present either as discarded commercial chemical product or manufacturing chemical intermediate. As such, the SW and TM-SW would be contaminated with listed hazardous waste number P012.

2.1.2.6 Derived from Rule

Residues from the treatment of listed hazardous waste or mixtures of solid waste and listed hazardous waste retain their hazardous waste status regardless of the concentration or form of contaminants remaining in the waste. Consequently, the SW would retain its hazardous waste status even after treatment with the MBS process, or any other process.

2.1.2.7 Delisting

While the treatment of mixtures of listed hazardous and nonhazardous waste using the MBS process does not automatically remove the residue from regulation as a hazardous waste, it may make the waste more amenable to redesignation as nonhazardous via the delisting process [3]. For onsite actions, the substantive requirements of the delisting process, including sampling and determination of the potential hazard of the treated waste, must be met. If the waste is being sent offsite, the administrative requirements also must be followed. The delisting regulations are presented in 40 CFR 260.20 and 260.22. The SW, once treated, could be a candidate for delisting, if it can be shown that the MBS process successfully reduces the leachable concentrations of all contaminants of concern (via TCLP and MEP testing).

2.1.2.8 Contained-In Policy

Although mixtures of listed hazardous waste and nonhazardous waste are considered hazardous waste, even after treatment, listed hazardous waste contained in media (i.e., soil, groundwater, or surface water) causes the combination to be regulated under Federal hazardous waste regulations only until the media no longer contain the hazardous waste. This “contained-in” policy removes the need for obtaining a delisting for treated soil and water. The determination of whether a medium no longer contains a listed hazardous waste is made by the EPA Region or an authorized State [4]. Since this determination could be made based upon the leachability of listed wastes, the MBS process could treat contaminated soil to the point where the soil is considered to no longer contain a listed waste. The contained-in policy, therefore, can greatly increase the cost-effectiveness of treating media contaminated with listed hazardous waste. This policy may apply to SW and TM-SW, if they are found to contain a listed waste. If this policy does not apply to wastes identified at the Midvale Slag Superfund Site, its importance as TBC material at other sites is noteworthy.

2.1.2.9 Characteristic Hazardous Waste

The Federal hazardous waste regulations identify four characteristics of solid waste that, if displayed, make the waste hazardous. The characteristics of ignitability, corrosivity, reactivity, and toxicity are described in 40 CFR 261.21 through 261.24. Of the four, the toxicity characteristic appears to be the one that will be displayed most often in waste and soil to be treated by the MBS process. The toxicity characteristic is a measure of the leachability of 8 metals and 32 organic compounds when exposed to liquid formulated to simulate nonhazardous landfill leachate using the TCLP test. If any of the 40 contaminants is present in the leachate in concentrations equal to or greater than the limits specified in 40 CFR 261.24, the waste is subject to hazardous waste regulation. Untreated samples of the SF, SB, SW, and TM-SW all displayed the toxicity characteristic due to the concentrations of leachable Pb, and the untreated SW also exceeded regulatory levels for leachable Cd.

Characteristic hazardous wastes are not subject to the mixture rule, derived from rule, delisting requirements, or the contained-in policy as are listed hazardous wastes. Instead, characteristic hazardous wastes, mixtures of nonhazardous wastes and characteristic hazardous wastes, and media containing characteristic hazardous wastes are no longer subject to Federal hazardous waste regulations once the wastes or media no longer display any hazardous characteristic. The SF and SB treated during the SITE demonstration should become nonhazardous wastes when the concentrations of TCLP leachable Pb decrease to below 5.0 mg/L and no other characteristic is displayed. SW and TM-SW, however, if determined to contain a listed waste, would remain hazardous until delisted or determined to no longer contain a listed waste.

2.1.2.10 Generator Requirements

Once it is determined that the material to be treated meets the definition of hazardous waste, the substantive requirements of the Federal hazardous waste regulations become ARARs. Requirements for generators of hazardous waste are found in 40 CFR 262. Substantive requirements include proper storage, training, and compliance with Land Disposal Restrictions (LDRs). The LDRs are discussed later in this subsection. If the waste is being transported offsite, both the substantive and administrative requirements of the Federal hazardous waste regulations apply to the shipments, including the use of a manifest and licensed hazardous waste transporter.

2.1.2.11 Treatment Requirements and Temporary Units

Treatment of hazardous waste at CERCLA sites must meet the substantive requirements of a hazardous waste treatment (referred to as a Part B) permit. These requirements are presented in 40 CFR 264 and 265 and include standards for treatment units, waste analysis, training, and security measures. Treatment of hazardous waste at non-CERCLA sites may only be performed after meeting the substantive and administrative requirements of the Part B permit process. Use of the MBS process at the Midvale Slag Superfund Site would have to meet the substantive requirements of a Part B permit as an ARAR. For sites undergoing remediation through the RCRA Corrective Action Program, the EPA Regional Administrator may approve the use of temporary units (TUs) for the treatment of remediation wastes. TUs are subject to reduced requirements that facilitate implementation of remediations [5]. The MBS process equipment may be eligible for designation as a TU when used at RCRA Corrective Action sites.

2.1.2.12 LDRs

Concerned with the continued toxicity of land-disposed

hazardous waste, EPA adopted the LDRs found in 40 CFR 268. These regulations stipulate management and treatment standards for both listed and characteristic hazardous wastes that are to be land disposed. Treatment standards are generally based on best demonstrated available technologies (BDATs) and either specify the technology to be utilized or the concentrations below which the identified hazardous constituents must be present before the waste may be land disposed. The triggering action for LDRs is the “placement” of hazardous waste into a land disposal unit, such as a landfill, surface impoundment, waste pile, or underground mine. Placement occurs when hazardous waste is: consolidated from different hazardous waste units (e.g., waste piles) into a single unit; moved outside a unit (for treatment or storage, for example) and returned to the same or a different unit; or excavated within a unit, treated by another hazardous waste unit (e.g., an incinerator or pugmill) located within the original unit, and redeposited into the original unit. Treatment in situ, in-place capping, intra-unit consolidation, and some types of processing designed to improve structural stability are not considered placement and do not trigger the LDRs [6]. Excavation of wastes at the Midvale Slag Superfund Site, followed by treatment in the MBS unit and redeposition to the site, would constitute placement.

The LDRs are ARARs for many CERCLA actions. For the wastes treated during the SITE demonstration, As, Cd, and Pb were the hazardous constituents that were evaluated. The untreated SF, SB, SW, and TM-SW all displayed the toxicity characteristic due to the concentrations of TCLP leachable Pb, and the untreated SW also exceeded regulatory levels for leachable Cd. The SW and TM-SW reportedly also contain discarded As trioxide product (a listed hazardous waste). The corresponding LDR treatment standards are 5.0 mg/L of leachable As, 1.0 mg/L of leachable Cd, and 5.0 mg/L of leachable Pb (the same TCLP concentrations that make the waste characteristically hazardous). Since the concentrations of leachable As and Pb in all four treated wastes were below the LDR limits, the treated wastes would not be prohibited from land disposal due to Pb or As content. The treated SF, SB, and TM-SW were also below the LDR limit for leachable Cd; however, the treated SW exceeded the LDR limit for leachable Cd.

Application of the MBS process to other wastes, or at other sites, may produce wastes that are effectively treated but still display concentrations above LDR limits. Recognizing that the LDRs were adopted primarily to address hazardous wastes generated from ongoing industrial operations, EPA has developed several mechanisms to facilitate cleanups at

CERCLA and RCRA corrective action sites within the requirements of the regulations. These mechanisms include soil and debris treatability variances, areas of contamination (AOCs), and corrective action management units (CAMUs).

2.1.2.13 Treatability Variance

When soil or debris from CERCLA actions differs significantly from the type of waste used to set the applicable LDR treatment standards, a treatability variance may be obtained [7]. The treatability variance provides alternate concentrations, or percent reductions for constituents based on prior experience with the treatment of soil and debris. Onsite actions are required to comply with the substantive portions of a variance. If the waste is to be transported offsite, both the substantive and administrative aspects must be addressed [8]. Based upon the results from the SITE demonstration, a treatability variance would not be required for disposal of the four treated wastes.

2.1.2.14 AOCs

An AOC is delineated by the areal extent of contiguous contamination. For the purposes of compliance with LDRs, an AOC is equivalent to a hazardous waste unit (e.g., a landfill). As such, the concept of placement applies to an AOC in the same manner as other units. This approach allows certain activities to take place within an AOC, such as waste consolidation, without triggering LDRs [6].

2.1.2.15 CAMUs

CAMUs were originally proposed as the RCRA corrective action equivalent of AOCs. Their application, however, is more formal. A Regional Administrator must designate an area as a CAMU. CAMUs must be incorporated into RCRA permits or orders, when these documents are required. The final rule codifying their status as a hazardous waste unit expanded the list of activities that could be performed without triggering placement over those identified in the proposal [5]. For example, remediation wastes originating from outside a CAMU may be consolidated into a CAMU without triggering LDRs. Similarly, wastes excavated from a CAMU may be treated inside or outside a CAMU and redeposited into a CAMU without invoking LDR requirements. Although the Midvale site is not being addressed under the RCRA corrective action program, designation of CAMUs and TUs at other sites where the MBS process could be used might be an ARAR.

2.1.3 CAA

CAA establishes primary and secondary ambient air quality standards for the protection of public health and emission limitations for six criteria air pollutants designated by the EPA. Requirements under the CAA are administered by each State as part of State Implementation Plans developed to bring each State into compliance with the National Ambient Air Quality Standards (NAAQS). Possible air emissions from use of the MBS process include dust, H₂S, other sulfide compounds, and volatile organic compounds present in the material being treated (the MBS reaction is exothermic). During the SITE demonstration, MBS treatment produced detectable concentrations of H₂S in the pugmill, and a sulfur odor was detected downwind of the site. Solucorp utilized a wet-scrubber system to control sulfur compound emissions during the demonstration. Dust emissions were also detected adjacent to the material-handling components of the equipment. While dust (including particulates with a diameter less than 10 microns, or PM₁₀), H₂S, and sulfur dioxide emissions are regulated under the CAA, the MBS equipment would not be considered a major stationary source. Use of a larger-scale MBS unit may require additional air emissions modeling and monitoring. State and local regulations may require the installation and operation of additional pollution control equipment to meet more stringent limits and reduce sulfur odors. Additionally, State and local air toxics rules may require monitoring for other compounds, including metals associated with particulates. (Note: The effectiveness of the wet scrubber was not evaluated during the demonstration.)

2.1.4 SDWA

SDWA establishes primary and secondary national drinking water standards. CERCLA incorporates these standards and Section 121(d)(2) explicitly mentions two of these standards for surface water or groundwater: Maximum Contaminant Levels (MCLs) and Federal Water Quality Criteria. Alternate Concentration Limits may be used when conditions of Section 121 (d)(2)(B) are met and cleanup to MCLs or other protective levels is not practicable. Included in these sections is guidance on how these requirements may be applied to Superfund remedial actions. The guidance, which is based on Federal requirements and policies, may be superseded by more stringent promulgated State requirements, resulting in the application of even stricter standards than those specified in Federal regulations. The only contaminated water produced by the MBS process originates from the air pollution control process and from equipment decontamination. Unless this water is to be injected into groundwater at the site, including release to a cesspool, SDWA requirements should not be ARARs.

2.1.5 CWA

CWA regulates direct discharges to surface water through the National Pollutant Discharge Elimination System (NPDES) regulations. These regulations require point-source discharges of wastewater to meet established water quality standards. The CWA also provides a regulatory framework for State and local authorities to regulate discharges of wastewater to sanitary sewer systems. This is accomplished through authorized pretreatment programs.

If the contaminated water produced by the MBS air pollution control process and from equipment decontamination is discharged to a surface water body, the discharge must meet all ARARs of the NPDES program (40 CFR 122), including the substantive requirements of a NPDES permit. Since water from the treatment process would likely be discharged in batches instead of continuously, the water may need to be stored and tested prior to release. In order to meet NPDES discharge limits, treatment of the water may be required.

Depending on the location of the site, contaminated water from the air pollution control equipment or decontamination procedures could be discharged to a publicly-owned treatment works (POTW). This type of discharge typically is regulated according to the industrial wastewater pretreatment standards of the POTW. These standards are specified in 40 CFR parts 401-471 for certain industries. Since the water produced during treatment would not fall into one of the established categories, the pretreatment standards would be determined by the POTW and depend on site-specific parameters such as the flow rate to the POTW, the contaminants present, and the design of the POTW.

2.1.6 TSCA

TSCA grants EPA the authority to prohibit or control the manufacturing, importing, processing, use, and disposal of any chemical substance that presents an unreasonable risk of injury to human health or the environment. With respect to waste regulation, TSCA primarily focuses on the use, management, disposal, and cleanup of PCBs. Regulations for the management and disposal of PCBs are found in 40 CFR 761. Materials with less than 50 parts per million (ppm) of PCBs are classified as non-PCB, those with a PCB concentration between 50 and 500 ppm are classified as PCB-contaminated, and those with a PCB concentration greater than or equal to 500 ppm are classified as PCBs. While TSCA contains an anti-dilution provision, requiring the regulation of PCB cleanup materials under the same rules applicable to the concentration of PCBs spilled, CERCLA actions typically are allowed to manage PCB-contaminated materials under the rules applicable to the "as-found" concentration [9]. State PCB regulations, however, may be

more stringent than TSCA regulations. PCBs were not anticipated to be present at the demonstration site and, therefore, no PCB analysis was performed on untreated or treated materials. The MBS treatment would not remove or reduce (other than by dilution) the concentration of PCBs present in material being treated. If PCBs were present in concentrations equal to or greater than 50 ppm in materials to be treated by the MBS process at a CERCLA site, TSCA regulations addressing storage and disposal would be ARARs.

2.1.7 OSHA

OSHA requires personnel employed in hazardous waste operations to receive training and comply with specified working procedures while at hazardous sites. These regulations (29 CFR 1910) stipulate that workers must receive appropriate training to recognize hazardous working conditions and to protect themselves adequately from those conditions. This training typically includes an initial 24- or 40-hour hazardous training course and sub-sequent annual 8-hour refresher classes.

OSHA regulations also require the use of proper personal protective equipment (PPE) while in areas where exposure to chemical, physical, biological, or radiation hazards could occur. During demonstration of the MBS process at the Midvale Slag Superfund Site, levels of dust and H_2S were monitored. While concentrations of H_2S exceeded the OSHA time weighed average concentration of 10 ppm at vents to the pugmill, the threshold was not reached in breathing zones around the equipment. Dust readings did not exceed the demonstration threshold of 6 mg/m^3 during any monitoring cycle. Nonetheless, H_2S and dust emissions should be considered when establishing a health and safety program for use of the MBS process.

2.2 OPERABILITY OF THE MBS UNIT

The MBS technology is described in detail in Subsection 1.3. The core component of the system is the pugmill, in which the MBS agent is mixed with the soil. Before entering the pugmill, the excavated soil is screened and crushed, then conveyed to the hopper that feeds into the pugmill. The MBS agent is fed into the pugmill from a storage silo. After the soil and the MBS agent are mixed together in the pugmill, the treated soil is conveyed to a dump truck or storage pile.

The system is designed for continuous operation and achieved a 100 percent on-line time during the treatment of SW and TM-SW, which were the third and fourth wastes/soils treated, respectively. During the treatment of SF, which was treated first, the on-line time was 73 percent. Downtime during the treatment of the SF consisted of

approximately 1.5 hours due to conveyor clogging and malfunctioning and approximately 1.5 hours due to a frozen water pump. During the treatment of SB, which was treated second, the on-line time was 82 percent. Downtime during the treatment of SB consisted of approximately 0.5 hours to repair the auger (which delivered the MBS agent to the pugmill) and 1.5 hours to address electrical problems. These on-line times ignore delays associated with the delivery of the MBS agent from the supplier to the site. During the 18 days of the demonstration, more than 4 days were spent waiting for MBS agent to arrive.

Solucorp has proposed full-scale remediation of the Midvale Slag Superfund Site using two units, each having a maximum capacity of 500 tph. The full-scale treatment scenario assumes that two such units will be operated in different areas of the site and will jointly provide an average throughput of 5,000 tpd. This scenario also assumes that treatment will occur 12 hours per day, 5 days per week. One foreman, two plant operators, four equipment operators, four truck drivers, two laborers, and one Health and Safety Manager will be required to operate the two plants. These positions will be staffed whenever treatment operations are being conducted; personnel will work 16 hours per day, 5 days per week. In addition, a Site Superintendent and a site Quality Assurance/Quality Control (QA/QC) Manager will each work 40 hours per week. One non-local field engineer will work 40 hours per week during the initial 2 weeks of operation. The duties of the plant operators will include routine inspection and replacement of mechanical parts, monitoring of operational parameters (e.g., flow rate), and sampling of the treated soil. These labor requirements do not include those for excavation/drying and screening/crushing activities. Wastes to be treated include: 250,000 yd^3 of SW; 108,900 yd^3 of SF; and 729,990 yd^3 of AQ slag. The total mass to be treated is approximately 2.07 million tons.

2.3 TECHNOLOGY APPLICABILITY

The applicability of the technology is very dependent on the characteristics of the soil present at the site. To estimate the applicability of the technology at a particular site, the developer recommends that site-specific treatability tests be performed before using the technology. Results of treatability studies performed for the Midvale Slag Superfund Site are presented in Appendix A. Appendix D contains vendor claims for the technology.

Case studies in Appendix C summarize the results of the use of the technology at different sites. These case studies and many of the vendor claims have not been independently evaluated by EPA-NRMRL or SAIC.

2.4 KEY FEATURES OF THE MBS

TECHNOLOGY

The patented Solucorp MBS process utilizes solid-phase chemical stabilization to reduce the leachability of metals (as measured by the TCLP method) in soils, slags, and other solid wastes. Solucorp claims that As, Cd, chromium (Cr), Cu, Pb, mercury, and Zn are rapidly converted to less-soluble metallic sulfides, and that certain metals (e.g., As), present in reduced forms, may require treatment with an oxidizing agent to improve treatment effectiveness. In addition, Solucorp claims that the MBS process, unlike some other immobilization technologies, does not modify the pH of wastes/soils to achieve chemical stabilization. This provides an advantage when treating multiple metals with different solubility points. Solucorp also claims that the MBS process involves a smaller volume increase than cement-based immobilization technologies, does not alter the physical properties of the soil during treatment, and does not require curing time.

2.5 AVAILABILITY AND TRANSPORTABILITY OF THE TECHNOLOGY

The primary components of the 60 tph unit used during the demonstration are trailer-mounted and can be transported using two flatbed trucks for the wet scrubber and miscellaneous equipment, one full-size tractor trailer for the pugmill, one stretch tractor-trailer for the conveyor (if the large conveyor is needed), and a pickup truck or other vehicle with a ball hitch to tow the silo. This unit and other smaller systems have been used at several sites, described in the case studies presented in Appendix C. Treatment rates cited in these case studies vary from 300 tpd to 400 tpd, which is slightly below the short-term treatment rates achieved during the demonstration.

The primary components of the proposed 500 tph unit will be trailer mounted, and it is projected that each unit will be able to be transported as 11 legal (not oversize) loads.

2.6 MATERIALS HANDLING REQUIREMENTS

Soil typically must be excavated and screened prior to treatment. As with other ex situ technologies, wet or clayey soils may require drying to improve material handling characteristics. During the demonstration, the SW and TM-SW were dried before screening. The excavated SW was tilled in lifts (layers) over a period of about 1 week to enhance drying. The excavated TM-SW was mixed with a trackhoe and allowed to dry for 1 to 2 days before it was screened. Large clumps of SF were broken up with a trackhoe before screening, but were not dried prior to screening.

SB did not require drying, screening, or crushing.

Apart from the treated soil, the only effluent from the system was vapor collected from inside the covered conveyors. This vapor stream was treated onsite using a wet scrubber. The demonstration did not include analyses of the scrubber emissions or the used scrubber water.

2.7 SITE SUPPORT REQUIREMENTS

The site must be prepared for the installation of necessary equipment. Access roads are needed for equipment delivery and installation. For the Midvale Slag Superfund Site, Solucorp has proposed full-scale remediation using two MBS units, each having a maximum capacity of 500 tph. A relatively flat area, at least 300 feet long and 100 feet wide, will be required for the construction of each 500 tph unit. A portion of the site may, therefore, require grading.

The site must also have space available for staging soil before and after treatment. Space requirements for staging untreated soil will depend on whether the soil needs to be dried and whether excavation is concurrent with treatment. It is projected that excavation will be conducted 16 hours per day, and (provided the soil does not require drying) there will be little or no staging of untreated soil. Space requirements for staging treated soil will depend on the frequency of soil sampling (assuming that analytical results proving that the soil meets regulatory limits must be available before the treated soil can be placed). For example, treatment of 5,000 tpd of soil will require about 28,000 square feet (ft²) of staging area per unit for treated soil pending confirmation that treatment has been successful. This scenario assumes samples are collected every day, analytical results are obtained in 2 days, and the average soil depth is 10 feet. Additional staging area will be needed if sample analyses require additional time.

Full-scale remediation using the MBS process requires that electricity and water be available at the site. It is projected that a diesel generator will be required to power auxiliary equipment. Water should be available to each unit at a flow rate of at least 75 gallons per minute (gpm).

A bermed area will be required for the decontamination of the unit. Decontamination of personnel will likely be minimal. However, water used in decontamination activities may be hazardous and its handling requires that a site plan be developed to provide for personnel protection and special handling measures. Storage should be provided to hold these wastes until they have been tested to determine their acceptability for disposal or release to a treatment facility.

2.8 LIMITATIONS OF THE TECHNOLOGY

The MBS process is designed to reduce leachable heavy metals concentrations. Other than dilution effects, total metals concentrations are not affected by the MBS process; therefore, treated wastes/soils with high total metals concentrations need to be handled to minimize short- and long-term exposure. Certain metals present in reduced forms (e.g., As) may require treatment with an oxidizing agent which Solucorp claims will improve treatment effectiveness. In addition, the vendor states that soils or wastes with high chloride content (in excess of 15 to 20 percent) cannot be effectively treated with this technology. As with other ex situ processes, this technology is most cost-effective for treatment of contaminants in shallow soils because the soils are readily accessible. However, excavation to greater depths, or use of in situ mixing may provide cost-effective applications of the MBS technology at certain sites. Soil/waste-specific treatability studies are recommended to determine the effectiveness of MBS at each site.

2.9 REFERENCES

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SECTION 3

ECONOMIC ANALYSIS

3.1 INTRODUCTION

The primary purpose of this economic analysis is to estimate the costs (not including profit) for using the MBS technology on a commercial-scale to remediate soil contaminated with Pb, As, and Cd.

3.2 BASIS OF ECONOMIC ANALYSIS

The cost analysis was prepared by breaking down the overall cost into 12 categories. The cost categories and the areas that each of them generally comprise are listed in Table 2. Because some of the cost categories are very site-specific, costs for these categories should be used with caution. Values presented in this section have been rounded to a realistic number of significant figures.

3.3 ISSUES AND ASSUMPTIONS

This subsection summarizes the issues and assumptions of the economic analysis for this study. Because several of the cost categories listed in Table 2 are affected by the total amount of time the system is operational, an estimate of cleanup time for a full-scale system is required.

For the economic analysis, the goal is to estimate remediation costs of a full-scale system used to treat 250,000 yd³ of SW/SWB; 108,900 yd³ of SF; and 729,990 yd³ of AQ slag. Using the density results from the demonstration, one would expect 372,000 tons of SW/SWB; 169,000 tons of SF; and 1,530,000 tons of AQ slag. The treatment time required to treat the entire mass is nearly 1.6 years based on an average throughput of 5,000 tpd.

Two continuous mixing plants at different locations on the site and adjacent to stockpiled material and areas of excavation will be employed. It is assumed that the full-scale

MBS unit will be scheduled to operate 16 hours per day, 5 days per week. An on-line factor of 75 percent (i.e., 12 hours per day of actual treatment) is assumed during treatment to compensate for the fact that the system can not be on-line constantly because of maintenance requirements, breakdowns, and unforeseeable delays. The total estimated time the equipment will be on site is approximately 444 work days (1.7 calendar years). This is based on the following time estimates:

<u>Activity</u>	<u>Work Days</u>
Assembly	10
Shakedown and Testing	5
Training	5
Treatment	414
Disassembly and Decontamination	10
TOTAL	444

According to the American Association of Cost Engineers, the actual cost is expected to fall between 70 percent and 150 percent of this estimate. Since this cost estimate is based on a preliminary design, the range may actually be wider. Subsections 3.3.1 through 3.3.12 describe assumptions that were made in determining project costs for the 12 cost categories. Costs for (1) permitting and regulatory activities; (2) residuals and waste shipping, handling, and transport; and (3) analytical services are highly dependent upon site-specific factors and, therefore, actual costs may vary widely. Consequently, the actual cleanup costs incurred by the site owner or responsible party can be significantly higher than the costs shown in this analysis.

Insurance, property taxes, operating supplies, contingency costs, and maintenance materials can be estimated as a percentage of the fixed capital investment required for a project [1]. The components of the fixed capital investment that apply to this project are the following:

- Total equipment cost applied to the project (including freight and sales tax)

Table 2. Twelve Cost Categories for the MBS Technology SITE Demonstration

1.	Site preparation	6.	Supplies
-	construction of equipment pad	-	operating supplies
-	utility connections	7.	Consumables
-	excavation and screening	-	electricity/fuel
2.	Permitting and regulatory	8.	Effluent treatment and disposal
-	actual permit costs	-	further treatment/disposal of effluent(s)
-	system monitoring requirements	-	onsite storage of effluent(s)
3.	Equipment	9.	Residuals and waste shipping, handling, and transport
-	equipment used during treatment	-	storage of residuals/wastes
-	freight	-	transportation of residuals/wastes
-	sales tax	-	treatment/disposal of residuals/wastes
4.	Startup and fixed	10.	Analytical services
-	transportation of personnel to the site	-	sampling and analytical program
-	wages and living expenses	11.	Facility modification, repair, and replacement
-	assembly of the unit	-	maintenance material costs
-	shakedown, testing, and training	-	design adjustments
-	working capital	-	equipment replacements
-	insurance	12.	Site demobilization
-	contingencies	-	disassembly costs
-	property taxes	-	site cleanup and restoration
-	process monitoring equipment	-	wages and living expenses
5.	Operating Costs for Treatment		
-	wages and living expenses		

- One year of operating supplies (1 percent of fixed capital investment)
- Transportation (other than freight)
- Site Preparation (other than excavation and screening)
- Assembly
- Shakedown, testing, and training
- Contingencies (10 percent of fixed capital investment)

Fixed capital investment is calculated as follows:

$$FP = \text{Fixed Capital Investment.}$$

$$FP = \sum(\text{independent variables}) + 0.01FP + 0.10FP$$

$$FP = \sum(\text{independent variables}) / 0.89$$

Since some of these components are estimated independently of the fixed capital investment (for example, assembly), and others are percentages of the fixed capital investment applied to the project (for example, contingencies), the fixed capital investment can be calculated by dividing the sum of the independent items by the factor 0.89, excluding the line items for 1 year of operating supplies (1

3.3.1 Site Preparation Costs

The amount of preliminary site preparation required is highly dependent on the site. Consequently, some site preparation costs are not included in this cost estimate and are assumed to be the responsibility of the site owner or responsible party. Costs that were considered for this analysis include the following: construction of two concrete pads, excavation, and screening. It is essential to consider that additional site preparation measures may significantly increase the costs associated with this category. The cost to construct two 20,000 ft² concrete pads is estimated to be \$160,000. Rental equipment for excavation and drying is estimated to be \$1,320,000 for the project and includes two crawler-mounted excavators, six dump trucks, two front-end loaders, and a generator. Labor and fuel costs for excavation/drying are \$3,179,000 and \$124,000, respectively. Rental equipment for crushing and screening is estimated to be \$1,330,000 for the project and includes two crushers, two portable vibrating screens, two front-end loaders, and four conveyors. Labor and fuel costs for crushing/screening are \$2,185,000 and \$59,600, respectively. It is assumed that excavation and screening activities will be conducted simultaneously with treatment. Site preparation activities are detailed in Table 3. The total estimated site preparation costs are \$8,360,000.

3.3.2 Permitting and Regulatory Costs

Permitting and regulatory costs can vary greatly because they are site- and waste-specific. For the purpose of this analysis, this category includes air treatment/discharge permit and construction permits. The cost of State and Federal air treatment/discharge permits for the scrubbers and reagent silos is estimated to be \$16,000 including labor for data review and estimating emissions, and permit fee. The cost of permits for onsite disposal of processed waste is assumed to be \$32,000. Local permits for construction, excavation, etc., are assumed to cost \$2,000. The total permitting and regulatory costs are assumed to be \$50,000.

- 300-barrel silos (total of six)
- Feed auger
- Short conveyor
- Long conveyors (two required)
- Belt scale
- Wet scrubber
- Blowers
- Miscellaneous pumps, valves, piping, and controls

Equipment cost estimates are based on vendor quotes, estimates from Solucorp, or information provided by engineering textbooks [1][2]. When necessary, the Chemical Engineering Cost Index [3] is used to estimate current costs from earlier cost data. The annualized cost (rather than depreciation) is used to calculate the annual equipment costs incurred by a site. The annualized cost is calculated using the following formula:

3.3.3 Equipment Costs

The primary pieces of equipment for each of the MBS mixing plants include:

- Pugmill (500 tph)

$$A = \frac{P(1+i)^n i}{(1+i)^n - 1} = \frac{P}{[1 - (1+i)^{-n}]/i}$$

where:

- A = annualized cost (\$)
- P = present value principal sum (\$)
- i = interest rate (percent)
- n = years

Table 3. Site Preparation Costs

Description	Quantity	Unit	Cost per Unit	Total Units	Total Cost	Cost per Treated Ton
Concrete Slab (100' x 200')	2	Ft ²	\$4	20,000	\$160,000	\$0.08
Excavation - Excavator/Backhoe	2	Month	\$11,000	19	\$420,000	\$0.20
Excavation - Dump Trucks	6	Month	\$3,500	19	\$400,000	\$0.19
Excavation - Front-end Loader	2	Month	\$13,000	19	\$490,000	\$0.24
Excavation - 10-KW Generator	1	Month	\$800	19	\$15,000	\$0.01
Excavation - Equipment Operator	4	Hour	\$45	6,624	\$1,192,000	\$0.58
Excavation - Truck Driver	6	Hour	\$40	6,624	\$1,590,000	\$0.77
Excavation - Laborer	2	Hour	\$30	6,624	\$397,400	\$0.19
Excavation - Fuel	1	Gallon	\$1.20	103,500	\$124,000	\$0.06
Screening - Crusher	2	Month	\$10,000	19	\$380,000	\$0.18
Screening - Screen	2	Month	\$5,000	19	\$190,000	\$0.09
Screening - Conveyor	4	Month	\$3,500	19	\$270,000	\$0.13
Screening - Front-end Loader	2	Month	\$13,000	19	\$490,000	\$0.24
Screening - Equipment Operator	6	Hour	\$45	6,624	\$1,788,000	\$0.86
Screening - Laborer	2	Hour	\$30	6,624	\$397,400	\$0.19
Screening - Fuel	1	Gallon	\$1.20	49,680	\$59,600	\$0.03
Total					\$8,360,000	\$4.04

The value "n" is the useful life of the equipment and varies according to the equipment under consideration. For this analysis, it will be assumed that the useful life of the MBS unit is 10 years and the interest rate is 9 percent. The annualized equipment cost is then prorated to the actual time the unit is at the remedial site (including assembly, shakedown and testing, treatment, and disassembly), which is 1.7 years for this analysis. The annualized cost is then divided by a utilization factor, in this case a factor of 0.5. This accounts for the fact that the vendor needs to expense the unit more during actual usage to cover times when it may be idle.

The cost for each 500 tph mixing plant is estimated to be approximately \$440,000. This includes reagent silos, feed system, scrubbers, blowers, conveyors, belt scale, and miscellaneous processing equipment (e.g., pumps, motors, controls, and piping). The equipment costs for both plants would be \$880,000.

Freight costs are assumed to be 6 percent of the total purchase cost and estimated to be \$52,800 for the project [2]. Sales taxes are assumed to be 5.5 percent of the total purchase cost and their costs are estimated to be \$48,400 for the project.

When the freight and sales costs are added to the equipment cost, the total equipment cost is estimated to be \$980,000. The annualized equipment cost for the 1.7 years the equipment is on the site is \$150,000. Assuming a utilization factor of 0.5 over the useful life of the equipment, the total equipment cost applied to the project is \$510,000. The equipment is assumed to have no salvage value.

3.3.4 Startup and Fixed Costs

Startup and fixed costs include the costs for transportation of personnel and equipment; assembly; shakedown, testing, and training; working capital; insurance; taxes; monitoring; and contingencies.

Transportation activities include moving the MBS technology and personnel to the site. Transportation cost for equipment, based on 22 legal loads transported 2,400 miles at \$1.65 per mile (with drivers), is \$87,000. Transportation of personnel is estimated to be \$2,100 and is based on three \$700 round-trip fares, two trips for the Field Engineer, and one trip for the Safety/QA Trainer. The total transportation cost is \$89,000.

Assembly includes unloading the system from the trailers and assembling it at the site. It is assumed that one hydraulic crane at \$2,000 per week will be required. The cost to transport the crane to and from the site is \$60 per hour, and it is assumed that it will take a total of four hours to deliver and pick up the crane. The cost of the crane is

estimated to be \$4,240.

Table 4 lists the fully-burdened costs (including wages, benefits, and overhead) and level of effort for all onsite personnel involved with assembly, shakedown and testing, training, and demobilization. Assembly should be completed within 10 days, shakedown and testing should take 5 days to complete, and training should be completed in 5 days. With the exception of the Field Engineer and Safety/QA Trainer, all employees are assumed to be local or will maintain residence near the site and will not be paid for travel or living expenses. The estimated labor cost for assembly, shakedown and testing, and training is \$123,000. Per diem for non-local employees is assumed to be \$80 and one rental car at \$50 per day is assumed. Per diem and rental car expenses for assembly, shakedown and testing, and training are \$2,800 and \$1,400, respectively.

Table 4. Wages and Levels of Effort for Labor During Startup and Demobilization

Job Title	Rate (\$/hr)	Assembly (hours)	Shakedown and Testing (hours)	Training (hours)	Demobilization (hours)
Superintendent	80	80	40	40	80
Foreman	60	80	40	80	80
Plant Operator	45	---	80	160	---
Equipment Operator	45	80	160	320	80
Truck Driver	40	---	160	320	---
Laborer	30	240	80	160	240
H & S Manager	50	80	40	80	80
QA/QC Manager	50	---	40	40	---
Field Engineer	75	80	40	40	80
Safety/QA Trainer	75	---	---	40	---

Working capital consists of the costs of borrowing capital for operating supplies, utilities, and labor necessary to keep the MBS unit operating without interruption due to financial constraints [1]. The working capital for this system is based on maintaining 2 months of payroll for labor and 1 month of inventory of the other items. The working capital cost is at 9 percent interest for the time the equipment is operating. The estimated required annual working capital cost is \$90,700. Therefore, the total working capital cost is \$154,000.

Insurance is assumed to be 2 percent of the fixed capital investment and the cost is estimated to be \$30,600 per year and \$52,000 for the project. Property taxes are assumed to be 3 percent of the total fixed capital investment [1] and the costs are estimated to be \$45,900 per year and \$78,000 for the project.

The total cost of process monitoring programs is estimated to be \$4,000 for the project. Types of process monitoring include qualitative and quantitative air monitoring for particulates and H₂S. It is assumed that field work will be performed by the technician and his/her labor costs will be covered in Subsection 3.3.5. Depending on the site, Federal, State, or local authorities may impose specific guidelines for monitoring programs. The stringency and frequency of monitoring requirements may have a significant impact on process monitoring costs.

A contingency cost is included to cover additional costs caused by unforeseen or unpredictable events, such as strikes, storms, floods, and price variations [1]. The project contingency cost is estimated to be 10 percent of the fixed

capital investment. The contingency cost is estimated to be \$153,000 for the entire project. The total startup and fixed costs for this project are \$662,000. Table 5 summarizes the startup and fixed costs.

3.3.5 Operating Costs for Treatment

It is assumed that MBS treatment operations will be conducted over 414 days, working 16 hours per day and 5 days per week. The 16-hour work day assumes 12 hours per day of treatment and 4 hours per day for setup, cleanup, personnel decontamination, and other daily activities. Fully-burdened costs (including wages, benefits, and overhead) and level of effort for all onsite personnel involved with treatment operations are given in Table 6. It is assumed that the Superintendent, QA/QC Manager, and Field Engineer will work a maximum of 40 hours per week. Furthermore, the Field Manager is non-local and will only be present for the first 2 weeks of operation. All other positions will work in 8-hour shifts in order to provide 16-hour coverage each day. The labor cost for treatment is estimated to be \$4,411,000. Per diem for non-local employees is assumed to be \$80, and one rental car at \$50 per day is assumed. Per diem and rental car expenses for treatment operations are \$1,120 and \$700, respectively. The total operating costs for treatment is \$4,413,000.

Table 5. Startup and Fixed Costs

Description	Quantity	Unit	Cost per Unit	Total Units	Total Cost	Cost per Treated Ton
Personnel Transport (round-trip)	1	Trip	\$700	3	\$2,100	<\$0.01
Equipment Transport	22	Mile	\$1.65	2,400	\$87,000	\$0.04
Crane Rental	1	Week	\$2,000	2	\$4,000	<\$0.01
Crane Delivery/Pickup	1	Hour	\$60	4	\$240	<\$0.01
Assembly Labor	1	Day	\$3,200	10	\$32,000	\$0.02
Assembly Per Diem	1	Day	\$80	14	\$1,120	<\$0.01
Assembly Car Rental	1	Day	\$50	14	\$700	<\$0.01
Shakedown & Testing Labor	1	Day	\$6,440	5	\$32,000	\$0.02
Shakedown & Testing Per Diem	1	Day	\$80	7	\$560	<\$0.01
Shakedown & Testing Car Rental	1	Day	\$50	7	\$350	<\$0.01
Training Labor	1	Day	\$11,840	5	\$59,000	\$0.03
Training Per Diem	2	Day	\$80	7	\$1,120	<\$0.01
Training Car Rental	1	Day	\$50	7	\$350	<\$0.01
Working Capital	1	Year	\$90,700	1.7	\$154,000	\$0.07
Insurance	1	Year	\$30,600	1.7	\$52,000	\$0.03
Property Taxes	1	Year	\$45,900	1.7	\$78,000	\$0.04
Monitoring Programs	1	Each			\$4,000	<\$0.01
Contingency	1	Each			\$153,000	\$0.07
Total					\$662,000	\$0.32

Table 6. Operating Costs for Treatment

Description	Quantity (per shift)	Unit	Cost per Unit	Total Units	Total Cost	Cost per Treated Ton
Superintendent ^a	1	Hour	\$80	3,312	\$265,000	\$0.13
Foreman	1	Hour	\$60	6,624	\$397,400	\$0.19
Plant Operator	2	Hour	\$45	6,624	\$596,200	\$0.29
Equipment Operator	4	Hour	\$45	6,624	\$1,192,000	\$0.58
Truck Driver	4	Hour	\$40	6,624	\$1,060,000	\$0.51
Laborer	2	Hour	\$30	6,624	\$397,400	\$0.19
Health and Safety Manager	1	Hour	\$50	6,624	\$331,200	\$0.16
QA/QC Manager ^a	1	Hour	\$50	3,312	\$165,600	\$0.08
Field Engineer ^{a,b}	1	Hour	\$75	80	\$6,000	<\$0.01
Per Diem	1	Day	\$80	14	\$1,120	<\$0.01
Car Rental	1	Day	\$50	14	\$700	<\$0.01
Total					\$4,413,000	\$2.13

a One 8-hour shift per day.

b The Field Engineer will only be present during the initial 2 weeks of treatment operations.

3.3.6 Cost for Supplies

For this project, supplies consist of operating supplies and MBS agent. Operating supplies include such items as charts, lubricants, custodial supplies, PPE, and other miscellaneous items not considered part of the maintenance materials. Annual operating supplies costs are estimated to be 1 percent of the fixed capital investment [1], which is approximately \$15,300 per year and \$24,500 for the entire project (1.6 years of treatment). Different MBS agent formulations will be used for each type of waste. The agent addition rates are based on the demonstration results and are 0.069, 0.070, and 0.135 for the SW/SWB, AQ slag, and SF, respectively. The cost for each agent is \$70.20/ton for the SW/SWB, \$50.00/ton for the SF, and \$65.00/ton for the AQ slag. These costs include blending but not freight. The MBS agent cost is estimated to be \$9,900,000. Assuming \$33/ton to ship by rail, the shipping cost is \$5,130,000. The MBS agent cost for the entire project (including freight) is

\$15,030,000. The total cost of supplies including MBS agent and miscellaneous operating supplies is estimated to be \$15,054,000. Table 7 summarizes the cost of supplies.

3.3.7 Cost for Consumables

During the SITE demonstration, two diesel generators will be employed to produce electricity for auxiliary equipment such as pumps, motors, and lights. Each mixing plant has a diesel motor to power the pugmill. The diesel fuel consumption during treatment is estimated to be 25 gallons per day per plant. Assuming \$1.20 per gallon for diesel fuel, the total cost for fuel for the project is \$25,000. Water is added during treatment to minimize dust. Assuming a water addition rate of 2 percent and a cost of \$2 per thousand gallons, the total cost of water for the project is \$20,000. The total cost for consumables for the project is \$45,000. Table 8 summarizes the consumables costs.

Table 7. Cost of Supplies

Description	Quantity	Unit	Cost per Unit	Total Units	Total Cost	Cost per Treated Ton
Miscellaneous Operating Supplies	1	Year	\$15,300	1.6	\$24,500	\$0.01
Reagent for SW/SWB	1	Ton	\$70.20	25,703	\$1,800,000	\$0.87
Reagent for SF	1	Ton	\$50.00	22,787	\$1,140,000	\$0.55
Reagent for AQ Slag	1	Ton	\$65.00	106,798	\$6,960,000	\$3.36
Shipping Cost (by rail)	1	Ton	\$33.00	155,288	\$5,130,000	\$2.48
Total					\$15,054,000	\$7.27

Table 8. Cost of Consumables

Description	Quantity	Unit	Cost per Unit	Total Units	Total Cost	Cost per Treated Ton
Diesel Fuel for Mixing Plants	2	Gallon	\$1.20	10,350	\$25,000	\$0.01
Process Water	1	Gallon*10 ³	\$2.00	9,936	\$20,000	\$0.01
Total					\$45,000	\$0.02

3.3.8 Cost for Effluent Treatment and Disposal

A wet scrubber will be used on each mixing plant to control H₂S emissions generated during processing. The capital and operating costs for this equipment are covered elsewhere. It is assumed that if sodium hypochlorite is periodically added to the scrubber water, its cost would be insignificant. The need for additional treatment systems will vary depending on the contaminants present in the soil and regulatory requirements at the site. Wash water from PPE decontamination may require treatment. Since these items are either site-specific or addressed elsewhere, they are not included in this report and are assumed to be the obligation of the site owner or responsible party.

3.3.9 Residuals and Waste Shipping, Handling, and Transport Costs

Residuals produced by the MBS technology can include treated waste, scrubber water and sludge, and wastes for the decontamination of equipment and personnel. It is estimated that treated waste can be placed, compacted, and capped onsite for \$5 per ton or \$11,200,000 for the entire project. The disposal cost for water and sludge from operation of the scrubbers is estimated to be \$2,000 for the entire project. One drum of PPE hazardous waste is expected every week. Assuming a disposal cost of \$500 per drum, the disposal cost for PPE is \$42,000. The total residuals and waste shipping, handling, and transport costs for

the project are \$11,200,000. Table 9 summarizes the total residuals and waste shipping, handling, and transport costs.

3.3.10 Cost for Analytical Services

The responsible party may elect or may be required by Federal, State, or local authorities to initiate a sampling and analytical program at its own expense. If specific sampling and monitoring criteria are imposed by Federal, State, or local authorities, these analytical requirements can contribute significantly to the cost of the treatment to confirm that the site has been successfully remediated. It is assumed that three composite analyses per day and an additional 10 percent for QA/QC will be required during treatment. With an assumed cost of \$225 per TCLP analysis, the estimated cost for analytical services is \$308,000 for the project. If more frequent sampling or other analyses are required, additional costs would be incurred.

3.3.11 Facility Modification, Repair, and Replacement Costs

Maintenance costs vary with the nature of the waste and the performance of the equipment and include costs for design adjustments, facility modifications, and equipment replacements. For estimating purposes, annualized maintenance costs (excluding labor) are assumed to be 3 percent of the fixed capital investment [1] and are estimated to be \$45,900 per year and \$78,000 for the project.

Table 9. Residuals and Waste Shipping, Handling, and Transport Costs

Description	Quantity	Unit	Cost per Unit	Total Units	Total Cost	Cost per Treated Ton
Landfill/Cap Treated Waste	1	Ton	\$5.00	2,230,000	\$11,200,000	\$5.41
Miscellaneous Scrubber Waste	1	Each	---	---	\$2,000	<\$0.01
PPE Waste	1	Drum	\$500	83	\$42,000	\$0.02
Total					\$11,200,000	\$5.43

3.3.12 Site Demobilization Costs

It is assumed that the equipment rental costs in the demobilization phase will be equal to the equipment rental costs of the assembly phase of the project. It is assumed that a total of 10 days will be required for disassembly of the above ground components and for preparation time needed to remove the equipment from the site. Labor rates and level of effort for demobilization are detailed in Table 4. The total labor cost for site demobilization including labor, per diem, and rental car is estimated to be \$34,000. The cost for a crane is estimated to be \$4,240 (see Subsection 3.3.4). The cost to transport the system offsite is estimated to be \$87,000 (see Subsection 3.3.4). The total cost for demobilization is \$125,000. Table 10 summarizes the site demobilization costs.

3.4 RESULTS OF THE ECONOMIC ANALYSIS

This subsection summarizes the results of the economic analysis of the MBS technology treating a site consisting of 2.07 million tons of SW/SWB, SF, and AQ slag. The two MBS mixing plants are assumed to be capable of treating 5,000 tpd. Table 11 summarizes the estimated treatment costs per ton of waste. Table 11 also presents the treatment costs of each of the 12 cost categories as a percentage of the total cost. The actual cost is expected to fall between 70 and 150 percent of the estimated cost based on the assumptions provided in Subsection 3.3.

Table 11 indicates that treatment of the wastes used for the demonstration (i.e., AQ slag, SW/SWB, and SF) using the MBS process will cost approximately \$20 per ton of waste at the Midvale Slag Superfund Site.

Table 11. Costs for Treating 2.07 Million Tons with 5,000 TPD Throughput

Item	Cost (\$/ton)	Cost (% of total cost)
Site preparation	4.04	20.5
Permitting and regulatory ^a	0.02	0.1
Equipment	0.25	1.3
Startup and fixed	0.32	1.6
Operating costs for treatment	2.13	10.8
Supplies	7.27	36.9
Consumables	0.02	0.1
Effluent treatment and disposal	0.00	0.0
Residuals and waste shipping, handling, and transport ^a	5.41	27.4
Analytical ^a	0.15	0.8
Facility modification, repair, and replacement	0.04	0.2
Site demobilization	0.06	0.3
Total operating costs	20	100

^a The cost for this item is highly dependent on site-specific factors.

The Region currently plans to treat 63,700 yd³ of CW and 250,000 yd³ of SW/SWB. All other wastes will be relocated and capped if necessary. Another economic analysis was performed for this scenario by assuming a chemical cost of \$91.20 per ton for the SW/SWB and \$105.90 per ton for the CW, a ratio of reagent to CW of 7.5 percent, a CW density

Table 10. Site Demobilization Costs

Description	Quantity	Unit	Cost per Unit	Total Units	Total Cost	Cost per Treated Ton
Equipment Transport	22	Mile	\$1.65	2,400	\$87,000	\$0.04
Crane Rental	1	Week	\$2,000	2	\$4,000	<\$0.01
Crane Delivery/Pick-up	1	Hour	\$60	4	\$240	<\$0.01
Demobilization Labor	1	Day	\$3,200	10	\$32,000	\$0.02
Demobilization per Diem	1	Day	\$80	14	\$1,120	<\$0.01
Demobilization Car Rental	1	Day	\$50	14	\$700	<\$0.01
Total					\$125,000	\$0.06

of 1.58 tons per yd³, and all other assumptions the same. The results of the second economic analysis are sum-

marized in Table 12. The cost for treating the CW and SW/SWB using the MBS process is estimated to be \$23 per

ton of waste at the Midvale Slag Superfund Site.

3.5 REFERENCES

1. Peters, M.S. and K.D. Timmerhaus. Plant Design and Economics for Chemical Engineers, Third Edition. McGraw-Hill, Inc., New York. 1980.
2. Baasel, W.D. Preliminary Chemical Engineering Plant Design. Elsevier Science Publishing Company, Inc., New York. 1980.
3. Chemical Engineering. McGraw-Hill, Inc. Volume 102, Number 1. January 1995.

Table 12. Costs for Treating 0.47 Million Tons with 5,000 TPD Throughput

Item	Cost (\$/ton)	Cost (% of total cost)
Site preparation	4.19	18.3
Permitting and regulatory ^a	0.11	0.5
Equipment	0.32	1.4
Startup and fixed	1.08	4.7
Operating costs for treatment	2.14	9.4
Supplies	9.04	39.5
Consumables	0.02	0.1
Effluent treatment and disposal	0.00	0.0
Residuals and waste shipping, handling, and transport ^a	5.53	24.2
Analytical ^a	0.15	0.6
Facility modification, repair, and replacement	0.05	0.2
Site demobilization	0.27	1.2
Total operating costs	\$23	100

a The cost for this item is highly dependent on site-specific factors.

SECTION 4

TREATMENT EFFECTIVENESS

This section discusses the effectiveness of the MBS technology during the SITE demonstration. Subsection 4.1 contains background information on the demonstration, including a discussion of predemonstration activities, a list of the nine demonstration objectives, and text addressing the treatment of a new batch of SW in June 1997. Subsection 4.2 contains a brief description of the methodology employed during SITE demonstration testing. Subsection 4.3 contains the demonstration results.

4.1 BACKGROUND

4.1.1 SITE Demonstration Testing - April/May 1997

The MBS process was tested on contaminated wastes/soils from the following three locations at the Midvale Slag Superfund Site (see Figure 2 for the waste locations): SF, SB, and SW. These wastes/soils were selected for demonstration testing based on results of initial site characterization sampling and treatability testing performed by Solucorp in January/February 1997. (Note: Site characterization and treatability study results are presented in Appendix A.) These wastes/soils had initial TCLP leachable Pb concentrations of three to five times the TCLP regulatory limit and were treated to less than the TCLP regulatory limit during the treatability studies.

The three wastes/soils were excavated, processed, and stockpiled for use in the demonstration during the week of February 10, 1997 according to the procedures defined in the February 4, 1997 Sampling and Analysis Plan (SAP), with minor field modifications [1]. Approximately 800 tons (roughly 500 yd³) were collected and stockpiled for each waste/soil. The SB was collected from a large pile (Pile B) that had been stockpiled during screening operations performed at the site from 1964 through 1992; the SF was excavated (to a depth of 4 to 5 feet) from the southern portion of the Floodplain SF Area; and the SW was excavated (to a depth of 6 to 8 feet) from the southern end of the SW Area near the access road from the Black Goose

Gate. Prior to treatment, all three wastes were stockpiled in the demonstration staging area, adjacent to where the Solucorp MBS equipment was later assembled. Prior to stockpiling, the SF was screened to less than 2 inches and the SW was spread, air dried/tilled, and screened to less than 2 inches.

Predemonstration samples were collected from each waste/soil as it was pretreated to verify the consistency and adequacy of contaminant concentrations; analytical results from these samples are presented in Appendix A. Composite samples were also collected during predemonstration activities as each waste/soil was pretreated; these samples were treated by Solucorp to optimize the MBS process for the demonstration.

Approximately 500 tons of each waste/soil were treated during the demonstration. Each waste/soil was processed at an estimated treatment rate of 60 tph. Although it took approximately 8 hours to treat each waste/soil, field activities lasted approximately 18 days. Approximately 2 days were spent on repairs, 4.5 days were spent awaiting the delivery of the MBS agent, and 6.5 days were spent on system startup, calibration checks, pretreatment activities, decontamination, and shutdowns.

The primary objective of the demonstration was to:

- 1) Demonstrate that the mean concentration of TCLP leachable Pb in each of three wastes/soils treated by the MBS process was less than the regulatory limit of 5 mg/L, at a 90 percent CL.

The eight secondary objectives of the demonstration were to:

- 2) Measure TCLP, SPLP, and total metals concentrations (As, Cd, and Pb) and pH in untreated

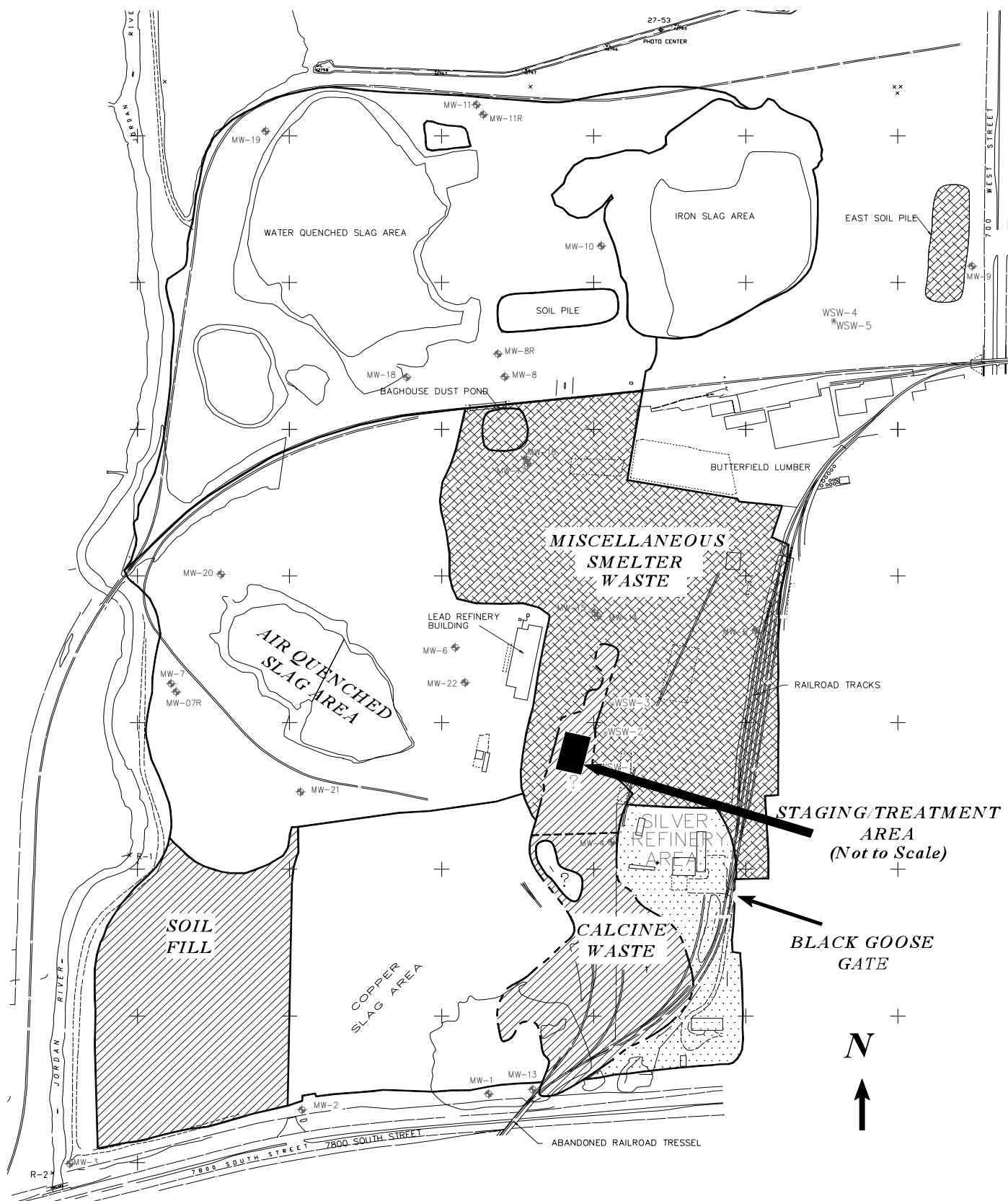


Figure 2. Site waste area locations - Midvale Slag Superfund Site.

wastes/soils. Results from these samples were

used as a "baseline" to interpret treated sample

results.

- 3) Measure TCLP metals concentrations (As and Cd) and pH (TCLP) in MBS-treated wastes/soils.
- 4) Measure SPLP and total metals concentrations (As, Cd, and Pb) and pH (SPLP and total) in MBS-treated wastes/soils.
- 5) Measure hydraulic conductivity and unconfined compressive strength (UCS) in the MBS-treated wastes/soils.
- 6) Measure density in the untreated and MBS-treated wastes/soils.
- 7) Measure the volume increase of each treated waste/soil that can be attributed to the MBS process using process measurements (mass throughput in tons, MBS agent addition in pounds, and water addition in gallons) and density measurements performed on treated and untreated sample composites.
- 8) Measure leachable metals (As, Cd, and Pb) concentrations in the leachate from an MEP test performed on each treated waste/soil.
- 9) Measure reactive sulfide in untreated and treated hourly composite samples.

Treated and untreated composite samples were collected and analyzed during the demonstration, as outlined in Subsection 4.2. Analytical results from these samples and process measurements collected during the demonstration were used to evaluate the objectives. TCLP Pb results in the treated samples were the only critical measurements, since they were the only measurements used to evaluate a primary objective.

4.1.2 SW Re-treatment - June 1997

A second batch of SW (designated TM-SW) was excavated, processed, and treated in June 1997. Solucorp funded the re-treatment of the SW after being notified that TCLP Cd concentrations in the treated SW exceeded the regulatory limit of 1 mg/L. The TM-SW was excavated, processed, and treated according to the procedures followed by the SITE Program during the original treatment of the SW in April/May 1997. The SW was re-treated reportedly using MBS agent with a higher purity sulfide component. To re-

duce analytical costs, however, the samples were only analyzed for total and TCLP As, Cd, Pb, and pH, and density. Although the samples were not collected as part of the SITE demonstration, EPA provided oversight, and SAIC provided field and technical support during the excavation, treatment, and analysis of the TM-SW. (Note: SAIC was under contract to Solucorp during the re-treatment of the SW.) TM-SW results have been included, as appropriate, in the tables in Subsection 4.3 and Appendix A.

4.2 METHODOLOGY

4.2.1 Field Procedures

Discrete samples of the untreated and treated waste/soil were collected after every 20 to 30 tons of treated material was processed. The sampling interval, in tons, was determined in the field, based on the amount of MBS agent provided for each waste/soil. Composites were generated after every other discrete sample. A total of 20 discrete and 10 composite samples were collected during the treatment of each waste/soil (both treated and untreated). One treated waste/soil composite, representative of each total run, was also collected by combining and homogenizing equal portions of the 20 discrete treated samples. Untreated soil was collected from the conveyer located between the hopper and the pugmill; treated soil was collected at the top of the second conveyer used to transport treated soil from the pugmill to the temporary storage pile.

All of the treated composites and half of the untreated composites (the odd-numbered composites) were analyzed for TCLP As, Cd, Pb, and pH. One half of the treated and untreated composites (the odd-numbered composites) were analyzed for total and SPLP As, Cd, Pb, and pH and reactive sulfide. Samples of the odd numbered composites were also forwarded to Kleinfelder for geophysical testing. The untreated geophysical samples underwent Proctor and density testing; the treated geophysical samples underwent hydraulic conductivity, UCS, Proctor, and density testing. (Note: The Proctor test was performed on the odd-numbered composites to determine optimum moisture and cylinder packing requirements for density testing.) The run composites were analyzed for MEP As, Cd, Pb, and pH.

Mass throughput (totalized in tons), the silo's auger speed (in hertz), and water addition (totalized in gallons) were monitored after each discrete sampling event. Mass throughput was obtained from the belt scale located on the conveyer leaving the pugmill; the auger speed was obtained from the auger hertz meter mounted on the side

of the silo; and water addition was obtained from a meter located upstream of the pugmill.

Belt scale and water meter calibration checks were performed before and after each run. Because the auger hertz meter did not provide MBS agent addition measurements in pounds (totalized), field personnel determined the hertz rate capable of delivering the appropriate MBS agent addition rate at the beginning of each run and then monitored hertz readings during treatment to make sure they did not change. At the end of the run, field personnel used the hertz rate monitored during treatment to confirm that the MBS agent addition rate had not changed.

4.2.2 Analytical Procedures

4.2.2.1 Metals

Untreated and treated waste/soil samples were extracted according to the guidelines outlined in SW-846 Method 1311, the TCLP, and SW-846 Method 1312, the SPLP[7]. Treated wastes/soils were also extracted using Method 1320, the MEP. In this procedure, the waste/soil was first extracted using the TCLP. Then subsequent extractions of the filtered solids were performed using the MEP extraction fluid (60/40 weight percent sulfuric and nitric acid to deionized water to pH 3.0 ± 0.2).

The leachates were then digested using SW-846 Method 3015, a microwave procedure. Finally, the digestates were analyzed by inductively coupled plasma (ICP) using SW-846 Method 6010A. To increase sensitivity, trace ICP, in which the plasma torch is positioned horizontally rather than vertically, was used.

Untreated and treated waste/soil samples were also digested for total metals using SW-846 Method 3050A, a hot acid hotplate digestion procedure. Again, the digestates were analyzed by trace ICP using SW-846 Method 6010A.

Initial calibration was performed daily using three standards and a blank. Standard concentrations covered the linear range for each element. The initial calibration was verified using a second source standard. Continuing calibration was performed after every 10 sample runs using a blank and the mid-level calibration standard. Interference check standards were run at the beginning and end of each run to verify the absence of spectral interference. Calibration requirements were met in all cases. Serial dilutions were analyzed on one untreated composite for each waste/soil as required by Method 6010A. Similarly, post-digestion spikes were analyzed for one treated composite for each

waste/soil. All samples were extracted and analyzed within the project-specified 180-day holding time.

4.2.2.2 Reactive Sulfide

Reactive sulfide analyses were performed as specified in Chapter 7, Section 7.3.4 of SW-846. An aliquot of waste/soil was added to $0.01 \text{ N H}_2\text{SO}_4$ in a closed system. The generated gas was swept into a scrubber. After 30 minutes, the scrubber contents were analyzed for sulfide by titration as described in SW-846 Method 9030A.

4.2.2.3 pH

The pH measurements for the leachates were performed according to the procedures in SW-846 Method 9040B. For the wastes/soils, SW-846 Method 9045C was used. Calibration was performed using pH buffers 4.0 and 7.0 or 7.0 and 10.0 as needed to bracket the sample pH.

4.2.2.4 Physical Tests

Density

A Proctor test (ASTM D1557) was performed to determine how the specimens should be compacted. The procedure was repeated for a sufficient number of water contents to establish a relationship between the density and water content for the sample (a compaction curve is prepared). The values of optimum water content and maximum density were then determined from the compaction curve. A soil sample at the optimum water content was compacted into a mold of given dimensions and the density (dry unit weight) was determined according to the procedures outlined in ASTM D698.

Hydraulic Conductivity

Hydraulic conductivity measurements were performed according to the procedures outlined in ASTM D5084. The falling head test, using a rising tailwater elevation (Method C), was employed.

UCS

UCS measurements were performed according to the procedures outlined in ASTM D2166. UCS was measured using strain-controlled application of the axial load. Four-point Proctor tests were performed to determine the cylinder packing requirements for density testing.

This subsection contains TCLP metals, SPLP metals, total metals, MEP metals, hydraulic conductivity, UCS, density, and reactive sulfide results for the treated and untreated

4.3 DEMONSTRATION RESULTS

demonstration samples. Percent solid and pH results, including soil pH and pH of SPLP and TCLP extracts, are reported in Appendix B. In general, mean values are reported in this subsection, and individual sample results are reported in Appendix B. The mean values are usually accompanied by either a CL, a confidence interval (CI), or a range. Adjusted mean concentrations, which account for decreases in As, Cd, and Pb concentrations due to the physical addition of MBS agent to the wastes/soils, are also reported in this subsection.

One-sided CLs (upper 90 percent CLs) are only reported for metals results which are compared to TCLP regulatory limits (i.e., TCLP, SPLP, and MEP metals results). Two-sided CIs (composed of an upper and lower 90 percent CL) are reported for metals results which are not compared to TCLP regulatory limits (i.e., total metals). Ranges are reported for geophysical results. (Note: Procedures for calculating one-sided CLs, two-sided CIs, and adjusted concentrations are located in Appendix B.)

4.3.1 TCLP Pb Results

The MBS technology reduced TCLP leachable Pb concentrations to below the TCLP limit of 5 mg/L during demonstration testing in April/May 1997. As shown in Table 13, upper 90 percent CL concentrations of TCLP Pb dropped from 33, 20, and 46 mg/L in the untreated SF, SB, and SW, respectively, to 0.20, 1.0, and 3.4 mg/L in the treated wastes/soils. Adjusted upper 90 percent CL concentrations were slightly higher (i.e., 0.23, 1.1, and 3.6 mg/L, respectively), but remained below the TCLP limit.

Although TCLP Pb concentrations were relatively consistent within the sample sets, some variability was experienced (see Figure 3). For example, TCLP Pb concentrations in treated SB samples collected at the end of the run (i.e., the last four samples) were on average four to five times higher than TCLP Pb levels in the six treated samples collected at the beginning of the run (i.e., 1.4 mg/L versus 0.26 mg/L, respectively). A similar trend was noted with the treated SW samples: the average TCLP Pb for the first six samples was 1.8 mg/L and the average TCLP Pb for the last four samples was 4.0 mg/L.

Table 13. TCLP Pb Concentrations, mg/L

Waste/Soil	Untreated	Treated	Adjusted
SF^a			
MEAN	28	0.18	0.20
UPPER 90% CL	33	0.20	0.23
SB^b			
MEAN	17	0.70	0.75
UPPER 90% CL	20	1.0	1.1
SW^c			
MEAN	36	2.7	2.9
UPPER 90% CL	46	3.4	3.6
TM-SW^d			
MEAN	15	0.33	0.35
UPPER 90% CL	17	0.40	0.43

- a The dilution factor used to calculate the adjusted Pb concentration in the treated SF was 1.135, as shown in Subsection B.2.
- b The dilution factor used to calculate the adjusted Pb concentration in the treated SB was 1.070, as shown in Subsection B.2.
- c The dilution factor used to calculate the adjusted Pb concentration in the treated SW was 1.070, as shown in Subsection B.2.
- d The dilution factor used to calculate the adjusted Pb concentration in the treated TM-SW was 1.067, as shown in Subsection B.2.

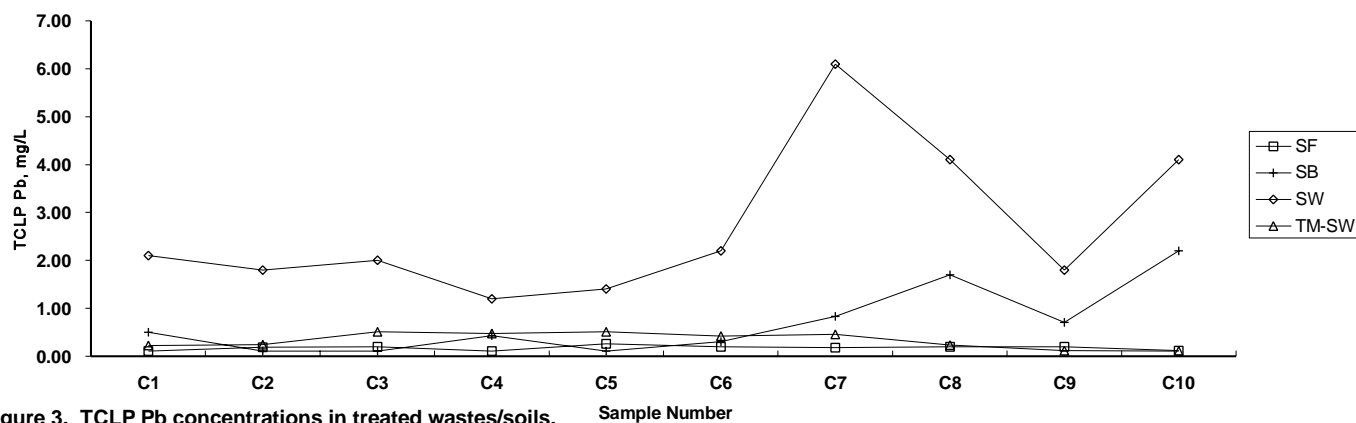


Figure 3. TCLP Pb concentrations in treated wastes/soils.

As noted in Subsection 4.1.2, Solucorp funded the excavation, processing, and treatment of a new batch of SW

(the TM-SW) in June 1997, after being notified that TCLP Cd concentrations in the treated SW exceeded the

regulatory limit of 1 mg/L. During the re-treatment of the SW, upper 90 percent CL concentrations of TCLP Pb in the TM-SW decreased from 17 mg/L in the untreated waste/soil to 0.40 mg/L in the treated waste/soil. Solucorp attributes the eight-fold reduction in the mean TCLP Pb concentration (i.e., from 2.7 mg/L in the treated SW to 0.33 mg/L in the treated TM-SW) to the higher purity sulfide component in the MBS agent. It should be noted that the mean TCLP Pb concentration in the untreated TM-SW was slightly less than half of the corresponding concentration in the SW. However, it is unlikely that this decrease in initial concentration is wholly responsible for the improved treatment results. TCLP As and Cd concentrations in the treated TM-SW were also lower than in the treated SW, as discussed in Subsection 4.3.2.

4.3.2 TCLP As and Cd Results

As shown in Table 14, the mean TCLP As concentration increased slightly with treatment, but remained below the TCLP As limit of 5 mg/L in each of the treated wastes/soils. According to Solucorp, treatment with an oxidizing agent should prevent future increases in leachable As (TCLP and SPLP) concentrations.

The TCLP Cd concentrations in the untreated and treated SF and SB were consistently below the TCLP limit of 1 mg/L. The mean concentration did, however, decrease slightly with treatment, from 0.57 and 0.31 mg/L in the untreated SF and SB to 0.056 and 0.084 mg/L in the treated SF and SB.

Although mean TCLP Cd concentrations in the SW decreased from 2.1 to 1.1 mg/L during treatment, the mean TCLP Cd concentration in the treated SW remained above the TCLP regulatory limit. Solucorp claims that they were unable to reduce TCLP Cd in the treated SW to below the TCLP limit because their supplier provided substandard MBS agent during demonstration activities in April/May 1997.

During the re-treatment of the SW in June 1997 (i.e., the TM-SW), Solucorp was able to reduce mean TCLP Cd concentrations from 0.5 to less than 0.01 mg/L. (Note: Mean TCLP As concentrations increased from 0.17 to 0.72 mg/L and mean TCLP Pb concentrations decreased from 15 to 0.33 mg/L during the treatment of TM-SW.) It should also be noted that although the mean TCLP Cd concentration in the untreated TM-SW composite was less than the TCLP regulatory limit, the relative decrease in the mean TCLP Cd levels was greater than the decrease experienced during the original treatment of the SW in April/May 1997.

Table 14. TCLP As and Cd Concentrations, mg/L

	As			Cd		
	Untreated	Treated	Adjusted	Untreated	Treated	Adjusted
SF^a						
MEAN	0.36 ^e	1.1	1.2	0.57	0.056	0.064
UPPER 90% CL	0.55 ^e	1.1	1.3	0.61	0.069	0.078
SB^b						
MEAN	0.22	0.46	0.49	0.31	0.084	0.090
UPPER 90% CL	0.35	0.54	0.58	0.34	0.11	0.11
SW^c						
MEAN	0.46 ^e	0.88	0.95	2.1	1.1	1.2
UPPER 90% CL	0.61 ^e	0.94	1.0	2.2	1.3	1.3
TM-SW^d						
MEAN	0.17 ^e	0.72	0.76	0.50	0.01 ^e	0.01 ^e
UPPER 90% CL	0.33 ^e	0.78	0.83	0.52	0.01 ^e	0.01 ^e

a The dilution factor used to calculate the adjusted concentrations in the treated SF was 1.135, as shown in Subsection B.2.

b The dilution factor used to calculate the adjusted concentrations in the treated SB was 1.070, as shown in Subsection B.2.

c The dilution factor used to calculate the adjusted concentrations in the treated SW was 1.070, as shown in Subsection B.2.

d The dilution factor used to calculate the adjusted concentrations in the treated TM-SW was 1.067, as shown in Subsection B.2.

e Calculated using reporting limits, rather than detected calculations.

4.3.3 SPLP As, Cd, and Pb Results

In all cases, mean and individual SPLP As, Cd, and Pb

concentrations in both the treated and untreated samples were well below the TCLP regulatory limits of 5 mg/L, 1 mg/L, and 5 mg/L, respectively, indicating that the SPLP method does not leach As, Cd, and Pb from the three

wastes/soils at concentrations which exceed the TCLP regulatory limits (see Table 15 for summary SPLP results). SPLP Pb, in particular, was never measured above its detection limit, preventing the observation of any measurable changes. A slight decrease in SPLP Cd concentrations was also noted in the SW; otherwise, no significant SPLP Cd changes can be noted.

As with TCLP results, mean SPLP As concentrations increased slightly with treatment (i.e., from 0.06, 0.07, and 0.06 mg/L to 0.39, 0.23, and 0.11 mg/L in the SF, SB, and SW, respectively). According to Solucorp, treatment with an oxidizing agent should prevent future increases in leachable As (TCLP and SPLP) concentrations.

4.3.4 Total As, Cd, and Pb Results

As shown in Table 16, total metals concentrations in the treated and untreated wastes/soils were similar. The results appear to indicate that the technology has little-to-no

impact on total metals concentrations, although, theoretically, the physical addition of MBS agent to the untreated waste/soil (between 7 to 14 percent MBS agent to soil by weight) should cause some soil/contaminant dilution. It is possible, however, that sample variability and waste/soil heterogeneity masked this effect

4.3.5 MEP Results

Treated wastes/soils passed EPA's MEP test; however, no conclusion can be drawn regarding the effect of treatment on long-term stability because leachable metals concentrations in the treated wastes/soils were equivalent to those in the untreated materials. As shown in Table 17 (see page 34), concentrations of As, Cd, and Pb in the MEP leachates from the treated wastes/soils were, with one exception, below the TCLP regulatory limits for As, Cd, and Pb. The only exception to this occurred when the sixth extraction of the SF sample (i.e., SF-F) was accidentally performed using the TCLP extraction fluid rather than the MEP extraction fluid. The resulting Pb concentration in leachate SF-F was 18 mg/L, which is significantly above the TCLP regulatory limit for Pb. Since these MEP metals concentrations in both the untreated and treated samples were reported at or near the detection limits, this appears to indicate that the MEP extraction fluid does not effectively leach metals from the three matrices treated during the demonstration.

Table 15. SPLP As, Cd, and Pb Concentrations, mg/L

	As			Cd			Pb		
	Untreated	Treated	Adjusted	Untreated	Treated	Adjusted	Untreated	Treated	Adjusted
SF^a									
MEAN	0.06 ^d	0.39	0.44	0.096	0.01 ^d	0.011 ^d	0.11 ^d	0.11 ^d	0.12 ^d
UPPER 90% CL	0.06 ^d	0.45	0.51	0.11	0.01 ^d	0.011 ^d	0.11 ^d	0.11 ^d	0.12 ^d
SB^b									
MEAN	0.07	0.23	0.25	0.01 ^d	0.01 ^d	0.011 ^d	0.11	0.11 ^d	0.12 ^d
UPPER 90% CL	0.085	0.30	0.32	0.01 ^d	0.01 ^d	0.011 ^d	0.12	0.11 ^d	0.12 ^d
SW^c									
MEAN	0.06 ^d	0.11	0.12	0.31	0.01 ^d	0.011 ^d	0.11	0.11 ^d	0.12 ^d
UPPER 90% CL	0.06 ^d	0.14	0.15	0.31	0.01 ^d	0.011 ^d	0.12	0.11 ^d	0.12 ^d

a The dilution factor used to calculate the adjusted concentrations in the treated SF was 1.135, as shown in Subsection B.2.

b The dilution factor used to calculate the adjusted concentrations in the treated SB was 1.070, as shown in Subsection B.2.

c The dilution factor used to calculate the adjusted concentrations in the treated SW was 1.070, as shown in Subsection B.2.

d Calculated using reporting limits, rather than detected calculations.

Table 16. Total As, Cd, and Pb Concentrations, mg/kg

	As			Cd			Pb		
	Untreated	Treated	Adjusted	Untreated	Treated	Adjusted	Untreated	Treated	Adjusted
SF^a									
MEAN	720	790	890	92	82	94	12000	11000	13000
UPPER 90% CL	920	1000	1100	98	85	96	13000	12000	13000
LOWER 90% CL	520	560	630	87	80	91	11000	11000	12000
SB^b									
MEAN	380	360	380	34	38	40	7600	7600	8100
UPPER 90% CL	550	410	440	45	51	54	8500	8100	8700
LOWER 90% CL	210	300	320	23	25	27	6700	7000	7500
SW^c									
MEAN	1700	1500	1600	120	100	110	12000	8900	9600
UPPER 90% CL	1800	1600	1700	140	110	120	16000	9100	9700
LOWER 90% CL	1600	1300	1400	100	91	97	9300	8800	9400
TM-SW^d									
MEAN	830	770	820	31	28	30	7400	6500	6900
UPPER 90% CL	900	900	960	33	29	31	7900	6700	7200
LOWER 90% CL	760	650	690	29	27	28	6900	6200	6600

a The dilution factor used to calculate the adjusted concentrations in the treated SF was 1.135, as shown in Subsection B.2.

b The dilution factor used to calculate the adjusted concentrations in the treated SB was 1.070, as shown in Subsection B.2.

c The dilution factor used to calculate the adjusted concentrations in the treated SW was 1.070, as shown in Subsection B.2.

d The dilution factor used to calculate the adjusted concentrations in the treated TM-SW was 1.067, as shown in Subsection B.2.

4.3.6 Treated Waste/Soil Hydraulic Conductivity and UCS Results

An examination of results in Table 18 indicates that the hydraulic conductivity of the SB was in general much higher than the conductivities measured for the SF and SW. This difference is probably due to the innate physical characteristics of the wastes/soils, rather than any impacts caused by the MBS process. (Note: SB is similar to road bed material and the SF and SW are comparable to a sandy-clay soil.) Table 18 also reveals that SF UCS results ranged from 7 to 13 pounds per square inch (psi); SW UCS results ranged from 3 to 14 psi. (Note: The SB samples could not be tested for UCS since the samples fell apart upon extraction.) Although the results provide some information on the physical characteristics of the treated wastes/soils, no conclusions can be drawn regarding whether hydraulic conductivity and UCS were affected by the treatment process, since untreated composites were not measured.

Table 18. Hydraulic Conductivity and UCS Measurements for Treated Wastes/Soils

Waste/Soil	Hydraulic Conductivity, cm/sec		UCS, psi	
	Mean	Range	Mean	Range
SF	1.4E-06	1.2E-07 to 2.9E-06	10	7 to 13
SB	2.1E-02	3.8E-08 to 3.8E-02	NA ^a	NA ^a
SW	6.0E-06	3.2E-06 to 9.3E-06	9.6	3 to 14

a The material was non-cohesive and fell apart upon extraction.

4.3.7 Density of Untreated and Treated Wastes/Soils

In general, density results were reasonably consistent within the untreated and treated sample sets. As shown in Table 19, the mean density of each treated material is only slightly different from the mean density of the corresponding untreated material.

Table 17. Metals Concentrations in MEP Leachates from Treated Soils and Single MEP Leachates from Untreated Soils

Waste Type- Extraction No.	Metals Concentrations in Leachate, mg/L			Final pH of MEP Extract
	As	Cd	Pb	
Untreated SF	0.06 ^a	0.16	0.17	7.11
Treated SF-A	1.0	0.07	0.12	5.20
Treated SF-B	0.08	0.02	0.11 ^a	6.29
Treated SF-C	0.06 ^a	0.01	0.11 ^a	6.61
Treated SF-D	0.06 ^a	0.02	0.11 ^a	6.09
Treated SF-E	0.06 ^a	0.04	0.11 ^a	6.44
Treated SF-F*	0.06 ^a	0.58	18	5.30
Treated SF-G	0.06 ^a	0.01 ^a	0.11 ^a	6.39
Treated SF-H	0.06 ^a	0.01 ^a	0.11 ^a	6.52
Treated SF-I	0.06 ^a	0.01 ^a	0.11 ^a	5.60
Treated SF-J	0.06 ^a	0.01 ^a	0.11 ^a	3.58
Untreated SB	0.06 ^a	0.08	0.11 ^a	6.83
Treated SB-A	0.56	0.06	0.11 ^a	4.98
Treated SB-B	0.06 ^a	0.01 ^a	0.11 ^a	4.76
Treated SB-C	0.06 ^a	0.01 ^a	0.11 ^a	5.62
Treated SB-D	0.06 ^a	0.01 ^a	0.11 ^a	3.77
Treated SB-E	0.06 ^a	0.02	0.11 ^a	2.87
Treated SB-F	0.06 ^a	0.03	0.11 ^a	5.58
Treated SB-G	0.06 ^a	0.02	0.11 ^a	6.40
Treated SB-H	0.06 ^a	0.01	0.11 ^a	6.60
Treated SB-I	0.06 ^a	0.01	0.11 ^a	3.95
Treated SB-J	0.06 ^a	0.01 ^a	0.11 ^a	6.55
Untreated SW	0.06 ^a	0.38	0.13	3.32
Treated SW-A	1.1	0.70	1.3	5.38
Treated SW-B	0.19	0.13	0.11 ^a	5.96
Treated SW-C	0.17	0.02	0.11 ^a	6.35
Treated SW-D	0.30	0.06	1.4	5.82
Treated SW-E	0.09	0.06	0.11 ^a	6.46
Treated SW-F	0.08	0.02	0.11 ^a	6.64
Treated SW-G	0.07	0.01	0.11 ^a	6.36
Treated SW-H	0.06	0.01	0.11 ^a	6.97
Treated SW-I	0.06 ^a	0.01	0.11 ^a	6.73
Treated SW-J	0.06 ^a	0.01	0.11 ^a	6.15

* TCLP fluid #2 mistakenly used instead of MEP fluid.

a Not detected at the reporting limit; number shown is the reporting limit.

Table 19. Density Measurements for Treated and Untreated**Wastes/Soils**

	Untreated, lbs/ft ³		Treated, lbs/ft ³	
	Mean	Range	Mean	Range
SF	115.0	112.5 to 118.5	113.2	111.0 to 115.0
SB	154.6	149.5 to 160.0	163.2	155.0 to 170.0
SW	110.2	107.9 to 112.0	107.7	105.0 to 110.0
TM-SW	113.2	112.0 to 114.5	108.7	107.0 to 112.5

lbs/ft³ = pounds per cubic foot

4.3.8 Volume Increase Due to MBS Treatment

The volume increase that can be attributed to the MBS process was calculated using density results and overall results from process measurements. The overall results (e.g., total mass of treated material, total mass of agent added, etc.) for each waste/soil were calculated using process measurements such as cumulative time (hours or hrs), cumulative mass of treated material (tons), MBS agent addition rate (lbs/minute or lbs/min), and cumulative water addition (gallons or gals). The overall results for each waste/soil were calculated based on the official run time, which began at the "official start" and ended with the collection of sample D20. Process monitoring data collected before the "official start" and after sample D20 were not used in the calculation of the volume increase.

The volume increase was calculated using the following equations:

$$VI, \% = \frac{V_T, yd^3 - V_U, yd^3}{V_U, yd^3} \times 100$$

$$V_T, yd^3 = \frac{M_T, tons}{\rho_T, tons/yd^3}$$

$$V_U, yd^3 = \frac{M_U, tons}{\rho_U, tons/yd^3}$$

$$M_T, tons = B_{D20}, tons - B_{START}, tons$$

$$M_U, tons = M_T, tons - M_W, tons - M_A, tons$$

$$M_W, tons = (V_W, gals)(\rho_W, \frac{lbs}{gal})(\frac{1 ton}{2000 lbs})$$

$$M_A, tons = (R_A, \frac{lbs}{min})(OT, hrs)(\frac{60 min}{1 hr})(\frac{1 ton}{2000 lbs})$$

$$V_W, gals = W_{D20}, gals - W_{START}, gals$$

$$OT, hrs = CT_{D20}, hrs - CT_{START}, hrs - CT_{LOST}, hrs$$

where:

B _{D20} =	cumulative mass reading on belt scale when sample D20 was collected, tons
B _{START} =	cumulative mass reading on belt scale at the official start, tons
CT _{D20} =	cumulative time on meter when sample D20 was collected, hrs
CT _{START} =	cumulative time on meter at the official start, hrs
CT _{LOST} =	total time when time meter was running but system was not processing waste, hrs
M _T =	mass of treated material, tons
M _U =	mass of untreated material, tons
M _W =	mass of water added, tons
M _A =	mass of agent added, tons
OT =	operating time, hrs
R _A =	rate at which agent was added, lbs/min
VI =	volume increase (percent)
V _T =	volume of treated material, yd ³
V _U =	volume of untreated material, yd ³
V _W =	volume of water added, gals
W _{D20} =	water meter reading when sample D20 was collected, gals
W _{START} =	water meter reading at the official start, gals
ρ _T =	average density of treated material, tons/yd ³ (see Table 19)
ρ _U =	average density of the untreated material, tons/yd ³ (see Table 19)
ρ _W =	density of water, 8.34 lbs/gal

In general, one average agent addition rate (R_A) was calculated for each waste/soil. The average agent addition rates were calculated using the auger calibration check results presented in Appendix B, Table B-17. However, auger repairs were performed during the treatment of SB. Concerns that these repairs could change the agent addition rate resulted in adjustments to the auger speed and additional calibration checks. As a result, seven different agent addition rates were calculated for SB.

The variations in agent addition rate observed during the treatment of SB made it necessary to use modified equations to calculate the mass of agent added during the treatment of SB. The following equations were used to calculate the mass of agent added during each time period of SB treatment:

$$M_{Aij}, lbs = \left(\frac{R_{Ai}, \frac{lbs}{min} + R_{Aj}, \frac{lbs}{min}}{2} \right) (OT_{ij}, hrs) \left(\frac{60 min}{1 hr} \right)$$

$$M_{Aij}, tons = (M_{Aij}, lbs) \left(\frac{1 ton}{2000 lbs} \right)$$

$$OT_{ij}, hrs = CT_j, hrs - CT_i, hrs - CT_{LOSTij}, hrs$$

where:

CT_i = cumulative time on meter at time i , hrs
 CT_j = cumulative time on meter at time j , hrs
 CT_{LOSTij} = total time between time i and time j when time meter was running but system was not processing waste, hrs
 M_{Aij} = mass of agent added from time i to time j , tons
 OT_{ij} = operating time between time i and time j , hrs
 R_{Ai} = agent addition rate at time i , lbs/min
 R_{Aj} = agent addition rate at time j , lbs/min

The total mass of agent added during the treatment of SB was calculated by summing the M_{Aij} 's.

Table 20 presents average volume increases and summarizes other process results for the four wastes/soils. Table 20 also presents the 90 percent CI associated with the calculated volume increases. The 90 percent CI associated with the volume increase was calculated based on the 90 percent CIs associated with the process measurements that were used to calculate the volume increase. The 90 percent CIs associated with the process measurements were calculated using the results of calibration checks performed during the operation of the MBS system. Detailed process measurements taken during the treatment of SF, SB, SW, and TM-SW are presented in Appendix B in Tables B-13, B-14, B-15, and B-16, respectively.

Mean volume increases for SF and SW were significantly higher than the "typical" 2 to 5 percent volume increases cited by Solucorp for other commercial applications. Only SB had a mean volume increase within this 2 to 5 percent range. The lower volume increase exhibited by SB may be related to the nature of the material. Because SB consists of relatively large (¼- to 1-inch diameter) pieces of incompressible material, much of the MBS agent can occupy

former void spaces. The other materials (SF and SW) are primarily compressible soils with minimal void space.

Table 20. Overall Process Results

Parameter	SF	SB	SW	TM-SW
Operating time (OT), hrs	8.1	8.9	8.0	7.7
Volume of water added (V_W), gals	1,041	2,650	3,792	3,287
Mass of water added (M_W), tons	4.34	11.1	15.8	13.7
Mass of agent added (M_A), tons	56.8	36.7	31.2	31.7
Mass of treated material (M_T), tons	483.3	573.5	495.4	516.4
Mass of untreated material (M_U), tons	422.2	525.8	448.4	471.0
Volume of treated material (V_T), yd ³	316	260	341	352
Volume of untreated material (V_U), yd ³	272	252	301	308
Mean volume increase (VI), %	16	3.3	13	14
90% CI for volume increase, %	8.8 to 24	-5.4 to 13	6.6 to 20	1.8 to 28

4.3.9 Reactive Sulfide in Untreated and Treated Wastes/Soils

Reactive sulfide was measured in the odd-numbered untreated and treated composite samples. Individual reactive sulfide sample results are summarized in Appendix B, Subsection B.3.8. Although the results were not adjusted for concentrations detected in titration blanks, the concentrations were still below the regulatory limit for reactive sulfide (i.e., 500 mg/kg).

4.4 QA/QC Summary

The QC results for the TCLP metals analyses were excellent. These QC results support the quality of the TCLP metals results which were used to evaluate the project's primary objective. Based on associated QC checks, the metals results for the total metals analyses, SPLP metals analyses, and MEP metals analyses are also of sufficient quality for evaluating the project's related secondary objectives.

With respect to reactive sulfide, QC results indicated potential problems with the results. Low LCS and matrix spike recoveries seem to indicate a low bias in the results. Reactive sulfide is defined as any sulfide which is released

under the specific conditions of the test. However, it is not obvious from the method that the sodium sulfide standard used for spiking should yield a recovery of 100 percent. In addition, reactive sulfide was observed in method blanks, which indicates that the sodium thiosulfate should have been restandardized; and the relationship of the iodine solution to the thiosulfate titrant re-established. The reactive sulfide results generated should be used with caution.

4.5 RESIDUALS

The wet scrubber used during the demonstration produced waste scrubber water, which the developer drained to a retention pond during disassembly. The Department of the Interior Bureau of Reclamation (BOR) was responsible for collecting this water in drums and testing it for disposal. Analytical results from these drums were not available when this ITER was written. These results should be used to determine whether the material is hazardous.

In general, vapor treatment residuals will be generated when using the MBS system. The classification and the material handling requirements for these residuals will vary

based on the design of the vapor treatment system and the contaminants present in the soil. For example, if a dry carbon vapor treatment system is employed, spent carbon may be a residual. Again, this medium will need to be analyzed to determine if it is nonhazardous.

Oversize material, which was been screened from the waste/soil prior to treatment, was also generated. This material was returned to the site without treatment. Quantities and disposal requirements at other sites will vary depending on the nature of the media requiring treatment (e.g., size and types of contaminants) and site replacement/disposal requirements.

4.6 REFERENCES

1. Final Predemonstration Waste/Soil Pile Characterization: Sampling and Analysis Plan for the SITE Demonstration of the Solucorp MBS Process at the Midvale Slag Site, Midvale, Utah. SAIC. February 1997.
2. Engineering Evaluation/Cost Analysis at the Midvale Slag Operable Unit 2 (OU2) Superfund Site, Midvale Utah. Volume 1, Site Characterization Report. May 1994.

SECTION 5

OTHER TECHNOLOGY REQUIREMENTS

5.1 ENVIRONMENTAL REGULATION REQUIREMENTS

State regulatory agencies may require permits for the on-site installation and operation of an MBS unit. An air emissions permit for construction and/or operation of the vapor treatment system may be required. If offsite disposal of contaminated residuals is required, the residuals must be removed from the site by a licensed transporter. These residuals must be treated or disposed of by a permitted (or similarly authorized) facility.

5.2 PERSONNEL ISSUES

Appropriate PPE should be available and properly utilized by all onsite personnel. PPE requirements will be site-specific and should be determined based on the contaminants present at the site and on the work activities being conducted. During the demonstration, PPE levels were designated according to the potential hazards associated with each work activity. At a minimum, Level D PPE was required for all personnel within the work zone. Level C PPE was worn by personnel collecting samples within the exclusion zone.

Site monitoring should be conducted to identify the extent of hazards and to document exposures at the site. Monitoring results should be maintained and posted. During the demonstration, a direct-reading dust monitor was used to monitor the air during excavation, treatment, and sampling activities. The lower action level for dust was 0.06 mg/m^3 above background levels. Respiratory protection (Level C PPE) was required above this level and optional below this level. The upper action level was 6.0 mg/m^3 above background levels for dust. When this level was exceeded, dust suppression techniques (such as application of water using a spray truck) were employed. The OSHA permissible exposure limits (PELs) for the MBS

agent are 15 mg/m^3 for the total dust time weighted average (TWA) and 5 mg/m^3 for respirable dust.

When the MBS unit was operating, dust monitoring was supplemented by H_2S monitoring. The lower action level for H_2S gas was 5 ppm. Breathing zone measurements collected during the demonstration did not exceed 5 ppm H_2S for any sustained period of time.

OSHA 40-hour training covering PPE application, safety and health, and emergency response procedures should be required for all personnel working with the MBS process. Additional training provided prior to the operation of the technology at a given site should include the following information: emergency evacuation procedures; safety equipment locations; the boundaries of the exclusion, contaminant reduction, and support zones; PPE requirements; and site- and technology-specific hazards. Potential hazards associated with the technology include personnel exposure to contaminated soil and dust particles during treatment. Safe operating procedures should always be observed.

Onsite personnel should participate in a medical monitoring program. Health and safety monitoring and incident reports should be routinely filed and records of occupational illnesses and injuries (OSHA Forms 102 and 200) should be maintained. Audits ensuring compliance with the health and safety plan should be carried out. In the event of an accident, illness, hazardous situation at the site, or intentional act of harm, assistance should be immediately sought from the local emergency response teams and first aid or decontamination should be employed when appropriate. To ensure a timely response in case of an emergency, workers should review the evacuation plan, firefighting procedures, cardiopulmonary resuscitation techniques, and emergency decontamination procedures before operating the system. An evacuation vehicle should be available at all times.

5.3 COMMUNITY ACCEPTANCE

Community acceptance of a technology is affected by both actual and perceived hazards. The only aspect of the MBS technology that may uniquely affect community acceptance is the potential for H₂S odors during treatment. The levels of H₂S gas measured during the demonstration did not present a health hazard, but the odor was noticeable. The other major factors that may impact community acceptance are common to most ex situ remediation technologies.

Dust from material handling, truck traffic, and treatment and stockpiling operations may be a concern to nearby residents, especially if total metals concentrations are high. Tarps and plastic covers for trucks and stockpiles have been effectively utilized to reduce dust problems. Dust suppression techniques, such as spraying water or foams on roads and in excavation areas, have also been utilized; the compatibility of any foam dust suppressants with the treatment process should be investigated. Screening operations and treatment processes can be partially contained to reduce fugitive dust emissions.

Noise may be a concern to the community if residential areas are close to remediation activities, especially if early morning or late evening work is planned. Primary sources of noise associated with the MBS technology are the electrical generator, drive motor, and hopper and silo vibra-

tors. At some sites, local electrical sources may be a practical alternative to use of a portable generator. Alternatively, the generator can be guarded with sound baffles or enclosed in a noise-insulated structure. Noise from the drive motor could be similarly ameliorated. The vibrators, used to ensure continuous flow of soil and MBS agent to the treatment system, produce a loud noise when the hopper and silo are not filled or void spaces occur. It is not likely much can be done to mitigate this noise problem. However, because these vibrators are not continuously used, this may not be a significant issue.

Truck traffic may be an issue if the site is located in a busy section of the community. Temporary street lights or other traffic control measures can be used to ensure safe conditions and minimize the inconvenience to local commuters. Mud and dirt carried out on truck tires can be an issue, but proper decontamination procedures will eliminate any associated hazard. Installation of gravel or paved access roads can minimize any aesthetic issues.

A Visitors' Day was held on April 15, 1997. The event was held at the Midvale City Building and included presentations by personnel from Solucorp, the City of Midvale, EPA Region 8, and EPA-NRMRL. A brief tour of the site was also conducted. Participants in Visitor's Day included regulatory personnel, remediation contractors, and members of the general public. This is an example of an activity to inform the public and improve community acceptance.

SECTION 6

TECHNOLOGY STATUS

Prior to the SITE demonstration, the MBS process had reportedly been implemented at several sites. In Glasgow, Scotland, the MBS process was used to treat soil contaminated with hexavalent and trivalent Cr. The MBS process was applied to Pb contamination from a pigment dye manufacturing site in New Jersey. The MBS process was

also applied to Pb- and Cd-contaminated soil and slag at a brass manufacturing site in Connecticut. In West Virginia, the MBS process was applied to a muddy Cu ash contaminated with Pb. These case studies are discussed in greater detail in Appendix C.